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Composite Helicopter
Accident Profiles -
Deficient Crew/Aircraft
Performance

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David L. Green

SAIC
Systems Control Technology Inc
1611 North Kent Street, Suite 910
Arlington VA 22209

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Final Report



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Dear Colleague:

Enclosed for your information is a copy of the recently published report **FAA/RD-94/22, Composite Helicopter Accident Profiles - Deficient Crew/Aircraft Performance**. The purpose of this report is twofold. First, it contains an analysis of a variety of rotorcraft operations that ended in collisions with terrain or man-made obstructions. Second, it provides insights into the affiliated technical and operational aspects of rotorcraft operations that contribute to this category of accidents.

The Army nap-of-the-earth mission dictates the need for an obstruction sensor and special training to ensure flight safety. The civil scenario is not so clear cut and the need for a dedicated obstruction sensor is not so obvious. While most civil accidents occur at low altitude, some were due to poor initial planning and poor judgment. Such poverty led some pilots to exceed their personal skill limits or the limits of their aircraft. The same result was also caused by following poor/inadequate procedures or by an inadequate appreciation of the factors affecting rotorcraft performance (eg. cross wind takeoff) or flying qualities. In other cases, air crews were subject to dangerous illusions whose effects could be mitigated through education and prudent new rules. A number of accidents indicate the need for improved instrumentation, airspeed and visual range sensors being the most notable.

We believe that rotorcraft collisions with obstructions can be prevented. Composite accident profiles are used in this report to illustrate the issues and to help identify opportunities for improved flight safety. This report should help both FAA and industry direct their efforts in ways that reduce the number of such accidents.

Robert D. Smith

for Richard A. Weiss
Manager, General Aviation and Vertical
Flight Technology Program Office

Technical Report Documentation Page

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16. Abstract The purpose of this report is twofold. First, the unique characteristics of a wide variety of helicopter operations which ended in a collision with terrain features or man-made obstructions were analyzed. Special emphasis was given to operations during difficult visual conditions. Second, this report provides the reader with systematic insights into the affiliated technical and operational aspects of helicopter flight operations which contributed to this category of accident.				
The report explores the way helicopters are flown in the low airspace and employs composite accident summaries as points of departure to both illustrate and substantiate the analysis which in turn identifies opportunities for improved flight safety and productivity in the National Airspace System (NAS). The included analysis deals with a series of rotorcraft accidents involving terrain and obstruction strikes. The common characteristics of these accidents support the need for specific changes. Each composite accident is illustrated and treated to an analysis which often allows the reader to focus on one characteristic in isolation. The summaries of these composite accidents and supporting analysis are included in the report to provide a common information base for the FAA analysts and industry engineers to support the need for additional equipment, new procedures, new products, additional training, and regulatory change.				
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EXECUTIVE SUMMARY

The growth of the civil and military helicopter community has been accompanied by an increasing number of accidents involving collisions with obstructions. Primarily these occurrences have involved wire strikes, surface impact and collisions with near earth obstructions (e.g., trees, power poles, buildings). Many have occurred under difficult visual conditions often accompanied by day/night inadvertent entry into IMC (e.g., recent series of Emergency Medical Service (EMS) and their Air Ambulance type accidents and incidents. In response to this situation, the Helicopter Obstruction Avoidance Technical Project Plan (HOATPP), DOT/FAA/CT-PP87/28, was prepared by ACD-230 and a draft was published in January 1988. The first objective of this plan was to develop the facts as best as could be established from official accidents reports and present this data in a format which would constitute a broadly understandable data base to support subsequent efforts to define practical and affordable solutions in the following areas: (1) Systems and Equipment; Forward/Downward Looking Sensor Systems, Flight Displays, and Helicopter Stability and Control; (2) Changes in Flight Operations; Procedures and Piloting Techniques, Means for Enhancing Detectability of Obstructions, FAA Certification, and Airspace Procedures and Regulations, (3) Crew Training, (4) Crashworthiness.

The first study undertaken in response to the HOATPP was initiated in April of 1989. This document reports the results of this effort which was accomplished in three phases as outlined below:

Phase I: Conducted an analysis of 150 of the most recent accidents involving collisions with terrain, natural micro terrain features and man made obstructions such as wires and towers.

Phase II: Correlated the common accident characteristics into a family of composite flight scenarios which collectively characterize the majority of obstruction strikes involving a serious accident.

Phase III: Analyzed each composite scenario to identify shortfalls. A discussion of each shortfall was developed to help readers understand the related needs.

The first four sections of the report contain a brief overview of unique helicopter characteristics and the environment within which the community operates. This includes an observation that most civil helicopter operations involve single engine aircraft, operated by a single pilot, under "difficult visual conditions" (DVC). The concept of DVC is introduced and discussed in some detail. Parallels are drawn between DVC flight operations and the environment encountered during the visual segment of an IFR approach. For example, while the crew is responsible for obstruction avoidance during DVC and protected airspace is utilized during an instrument approach, the flight guidance and visual aspects of flight profile management can be nearly identical. The next seven sections (5 through 11) present 23 composite accident scenarios. In brief, these scenarios and accompanying analyses suggest that:

- 1). Sometimes pilots fly into wires they are aware of, on a clear sunny day. This group of accidents includes some which involved maximum performance take-offs in cross winds (unknowingly attempted with insufficient power available). Other pilots are thought to have flown into wires because they used an in-ground-effect acceleration technique instead of a vertical departure technique. In

all cases, small increases in vertical agility (power to climb) would have allowed the aircraft to clear the wires.

- 2). Certain accidents involved reckless operations such as road following, river following below the river bank, and ridge crossing at tree top levels. Many pilots seemed to fly themselves into situations where they lacked the performance and maneuverability to fly up and over wires or other unexpected obstruction detected at close range. Some of these accidents highlight the fact that low time pilots, operating low performance helicopters, seem to lack an understanding of the limitations of their aircraft and the increase in safety which is gained by flying no lower than 300 feet AGL during en route operation (most wire strikes were at or below 100 feet, while the majority is below 50 feet AGL).
- 3). Many accidents appear to have involved illusions and human factors issues associated with helicopter cockpit design and the way helicopter attitude is varied to accelerate and decelerate. For example, analysis suggests that pilots unconsciously descend into obstructions during decelerating flares.
- 4). Slow speed disoriented flight and decelerating course reversals produced both loss of control and unnoticed loss of altitude followed by ground contact. Most of the accidents which occurred in deteriorating weather involved ground contact at slow speeds.
- 5). Poor navigation and route planning techniques were observed to cause crews to become lost. Upon encountering DVC, they would descend to increase their visual range. This descent would lead to an immediate wire strike or an attempt to reverse course with inadequate space for maneuvering, followed by disoriented flight and uncontrolled terrain contact.
- 6). Pilots were reported to have used lights to accomplish contact navigation at night. The range of the standard landing light is so short that pilots felt compelled to fly down to very low altitudes to enable the light to provide the needed illumination. At low altitude, with pilots looking down, even clearly visible wires would go undetected.

Many pilots seemed to fly too fast for the available visual range, but for some reason they did not realize what they were doing until it was too late. This was true for both day and night operations. This fact suggests the need for a sensor which will warn pilots that they are approaching an area of rapidly deteriorating weather. In other situations, improved stability, controls, displays, procedures and training would have decreased the propensity of pilots to become disoriented and fly into the ground during eyes-in, eyes-out flight while operating in DVC.

The report concludes that the concept of crew managed obstruction avoidance is one of the most important constructs of the rotorcraft and powered lift segment of the transportation system. That is, if rotorcraft are to continue to populate the lower airspace in a productive capacity, there will be an omnipresent priority need for the application of obstruction avoidance technology and techniques during all low altitude operations from takeoff to landing. This systematic consideration of obstruction avoidance includes both visual operations, and IFR operations with and without visual components. This situation exists because of the overriding need to minimize the need for protected airspace in all low altitude operations.

SECTION 1

INTRODUCTION

PURPOSE

The purpose of the effort reported herein, was twofold. First, the effort responded to a need to identify and analyze the unique or otherwise significant characteristics of a wide variety of civil helicopter operations which ended in a collision with terrain features or man made obstructions; with special emphasis being placed upon operations involving difficult visual conditions. Second, having conducted the analysis, this report was fashioned to provide the reader with systemic insights into the affiliated and sometimes interactive technical and operational aspects of helicopter flight operations which contributed to this category of accident. The objective of this approach being to present an understanding of causal factors which in turn could provide a basis for enhanced flight safety and a more complete exploitation of the attributes of helicopters in the National Airspace System (NAS), for the broad benefit of the rotorcraft industry and flying public.

BACKGROUND

The accident rate of the rapidly growing emergency medical services (EMS) helicopter industry and its related operations precipitated a safety study of 59 accidents by the National Transportation Safety Board (NTSB), the results of which were published in January 1988 (reference 1) and highlighted two facts:

- (1) A majority of EMS accidents (67 percent) were weather related, the predominant factor being restricted visibility. This is a situation which had been constant for 15 years (according to reference 2); and
- (2) (68 percent) involved pilot factors or poor judgement as a part of the probable cause.

Concomitant with the above NTSB study, a separate effort produced Advisory Circular Number 135-14, "Emergency Medical Services/Helicopter," (reference 3) which provided information and guidance in recognition of the then serious accident rate within that segment of the industry and the recognition that a substantial improvement could be achieved through the institution of improved certification requirements, training, and operational procedures. This circular referenced an FAA pamphlet, "Aeronautical Decision Making for Helicopter Pilots," (reference 4) which preceded a series of pamphlets developed especially to support EMS operations. This remedy was supported by findings of other accident studies including references 5 and 6. The series now includes:

- 1). "Aeronautical Decision-making for Helicopter Pilots," DOT/FAA/PM-86-45, NTIS: ADA 180 325 (reference 4);
- 2). "Aeronautical Decision-making for EMS Helicopter Pilots -- Learning from Past Mistakes," DOT/FAA/DS-88/5, NTIS: ADA 197 694 (reference 7);

- 3). "Aeronautical Decision-making for EMS Helicopter Pilots -- Situational Awareness Exercises," DOT/FAA/DS-88/6, NTIS: ADA 200 274 (reference 8);
- 4). "Risk Management For Air Ambulance Operators," DOT/FAA/DS-88/7, NTIS: ADA 212 662 (reference 9); and
- 5). "Aeronautical Decision-making for Air Ambulance Administrators," DOT/FAA/DS-88/8 (reference 10).

During the 1986 through 1987 time frame, the Helicopter Obstruction Avoidance - Technical Project Plan, was developed by ACD-230 and published in draft form in January 1988 (reference 11). This plan recognized that there was a need to structure a long term project to deal with the issues of restricted visibility and weather encounters during low altitude visual flight rules (VFR) operations. Expanding EMS operations provided the initial requirement for improved operational safety, but the passage of time revealed other operations with similar needs.

The growing utilization of rotorcraft in unique visual operations has been accompanied by an increasing number of accidents and/or incidents involving collisions with obstructions. Primarily these occurrences have involved wire strikes, surface impacts, and collisions with near earth obstructions such as trees, power poles, and antennas. Many incidents and accidents have occurred under difficult visual flight conditions that are encountered at night. Other daytime accidents have occurred in operations in rain, haze, fog, dust, and snow. Both day and night accidents involved speeds which were in excess of that which could safely be used for the stated scenarios. This sometimes resulted in operations characterized as inadvertent instrument flight rules (IFR). In some cases, the helicopter was not appropriately equipped and crewed. The crew was not able to operate safely in a difficult visual environment, or advance to a suitable IFR flight mode, or to execute a precautionary landing.

In addition, a number of accidents were identified which were not caused by difficult visual conditions but did support the need to develop a better understanding of how helicopters are flown during near terrain operations. Characteristics such as "power required" were first explored during clear day operations. This analysis often supported subsequent analysis of composite accidents involving difficult visual conditions.

Before going on, it is important to note that the EMS program has benefited immeasurably from the introduction of AC No. 135-14 and the series of aeronautical decisionmaking (ADM) pamphlets discussed above. This report and the efforts which will follow as a result of the Helicopter Obstruction Avoidance Project will expand upon the improvements already achieved by the earlier efforts, and focus on additional improvements, none of which are expected to conflict with either AC No. 135-14 or the ADM pamphlets.

OVERVIEW OF METHODOLOGY

This report explores the way helicopters are flown in the low altitude airspace and employs composite accident summaries as points of departure to both illustrate and substantiate the analysis which in turn identifies opportunities for improved flight safety and improved productivity in the NAS. The included analysis deals with a series of rotorcraft accidents involving terrain and obstruction strikes. The common characteristics of these accidents support the need for specific changes. Each composite accident is illustrated and treated to an analysis which often allows the reader to focus on one isolated characteristic. The summaries of these composite accidents and supporting analysis are included in the report to provide a common information base for Federal Aviation Administration (FAA) analysts and industry engineers to support the need for additional equipment, new procedures, new products, additional training, and regulatory change.

TECHNICAL REQUIREMENTS OF THE FAA

The FAA requires technical information in order to identify and evaluate the operational and research and development requirements for improving the rotorcraft operations safety, including the tiltrotor. This technical report contains pertinent data and testing/guidance material needed to support those elements of the agency charged with the performance of regulatory actions and the development of advisory materials and standards. This technical report includes expert analysis of rotorcraft accidents where obstructions were a factor and the development of the required technical and operational solutions.

SECTION 2

UNDERSTANDING THE HELICOPTER'S PLACE IN THE NATIONAL AIRSPACE SYSTEM

GENERAL

The question is often asked: Why don't helicopter pilots file IFR and integrate themselves into the IFR airways system? This is a good question because the pursuit of the answer leads the analyst to discover a multitude of differences between helicopters and airplanes. The related discovery process leads to a better understanding of how the civil helicopter community is evolving and how it can be profitably employed in the NAS.

In this context, the following provides a brief overview of unique helicopter characteristics and the environment within which the community operates. This should establish an initial understanding of the needs and potential benefits to be realized through enhanced safety.

INSTRUMENT FLIGHT ON AIRWAYS

The speed and range of the airplane allows it to fit into the NAS as IFR traffic easier than a helicopter. Furthermore, the airplane has evolved as an integral part of the airport-airways system which has been responsive to the needs of airplane operations. This facilitation of the airplane has required longer and wider runways, and more of them on larger and larger airports. The airways have similarly expanded to meet the needs of large and fast airplanes which must move in a very managed fashion to safely and economically meet the needs of the user community and ultimately the general flying public. This airways traffic management system works at night as it does in the daytime primarily because it is based upon flight under IFR in controlled airspace.

The helicopter can operate very effectively and safely under IFR conditions on airways to and from airports, but in many ways this is a misapplication of the helicopter. The cost and complexity of a helicopter is difficult to justify when it is only used in this way.

The robust vertical flight capability of the helicopter is its principal attribute. It is this attribute which must be utilized for the public good. A landing beside a highway to pickup a critically injured driver does represent a suitable exploitation of vertical flight, as does crew transfers to and from oil rigs in the Gulf of Mexico, and city-center to city-center transfer of priority packages.

The helicopter is evolving as a unique and increasingly capable member of the aviation transportation community. It is increasingly needed for transportation which is best accomplished within that portion of the airspace system which is contiguous with and/or close to the underlying terrain. That is, it is the aviation

platform which is best suited for rapid response, short haul operations. Such operations are generally not facilitated by high altitude IFR en route segments, although there are times when an IFR segment is appropriate. Although most of today's helicopter operations are conducted during the daylight hours, the future will probably involve a substantial increase in night operations. For example, helicopters can conduct many priority missions which are most likely to occur at night, such as emergency medical services, law enforcement, and delivery of express communications. It is the darkness of the night and the difficult visual conditions which typically accompany the night which combine to define much of what has come to be called difficult visual conditions.

Tiltrotor: Common Needs. Tiltrotor aircraft bring with them an enhanced speed capability which exceeds that of many airplanes, but they retain the robust hover capability of the helicopter. Thus the tiltrotor marries the attribute of speed to the robust hover capability of the helicopter. There is no need for the tiltrotor aircraft to conduct missions which are easily accomplished by either the airplane or the helicopter. It will work between heliports and vertiports (which will not support airplane operations) and operate over route segments which are too long for effective helicopter use. The "airplane-like" needs of the tiltrotor are nominally met by the existing and evolving NAS features designed to support airplane operations. It is the vertical flight portion of tiltrotor operations which is unique and requires development. Here the match with the helicopter is obvious. Both of these rotorcraft hover, and both are capable of robust slow speed maneuvers. Thus work which is accomplished for helicopters should (where practical) consider the eventual needs of civil tiltrotor aircraft.

VISUAL OPERATIONS OFF AIRWAYS

Day. The helicopter has been recognized to have the unique attribute of vertical flight. The airplane has no such capability. The ability to fly slower and slower, and finally hover if necessary has justified helicopter unique VFR minimums which are lower than those required for airplane operations.

Airplanes fly fast and stall at speeds that correspond to helicopter cruise speeds. For this reason airplanes need visibility and ceilings which will preclude the probability of inadvertent instrument meteorological conditions (IMC) operations or the need for aggressive maneuvers to avoid obstructions or other traffic.

Helicopters Hover. Helicopters also typically encounter retreating blade stall (or limit structural loads) at speeds that correspond to airplane cruise speeds. Helicopters can be designed to hover and maneuver extremely well at low speed, thus pilots of these aircraft can operate at an equivalent level of safety while flying with visual ranges which are shorter than required by comparably sized and equipped airplanes.

Night. Flying at night is just like day flying except the pilot can not see as well.

Navigation. Helicopter pilots need to see the route over which they fly to conduct macro and micro navigation. In a macro mode they need to see ridge lines and other

major landmarks to insure that the navigation system is nominally correct and to facilitate operations which are best conducted visually and do not require the precision of a navigation system. On some occasions, helicopters need to fly from point A to point B and electronic navigation signals are not available forcing the flight to be conducted via contact navigation means.

Typical contact micro navigation tasks involve the need to navigate along routes which minimize the aggravation caused by helicopter noise. Such a route may involve following a busy highway or a winding river which provides a suitable approach corridor to a heliport or remote landing site. Micro navigation is also important when the precise coordinates of the destination are not known but the location has been defined with respect to terrain features such as TV towers, bridges, road intersections and rail crossings.

See Traffic. In addition, pilots must see traffic. Other, VFR traffic typically involves light VFR airplane traffic and from time-to-time a helicopter.

See Weather. The pilot must know how to see weather at night and/or the pilot must have the ability to communicate with weather stations who have this information. The availability of these weather stations is decreasing annually and their number is further deminished after dark when many airports close.

Communications. Communication can also be very difficult during low altitude operation. This can introduce problems during efforts to respond to flight following requirements and during efforts to transition into the IFR portion of the NAS.

EXTERNAL LIGHTS

Some small helicopters have no flood or landing lights. Many have a single fixed light while others have a fixed landing light and a fixed taxi (hover) light. Some have a multi-position landing light and a few have a controllable spot light (much like the landing light but controllable). These lights are typically 150 or 300 watts, have limited range, and are intended to be used to facilitate takeoff and landing operations. More powerful search lights are installed for operations such as law enforcement and EMS.

SINGLE-ENGINE VS TWIN-ENGINE HELICOPTERS

The single-engine helicopter is subject to total power loss with little or no warning. The result is an immediate forced landing. The time between engine failure and touchdown ranges between 3 seconds, for a hover failure, and 15 to 20 seconds for a failure at 500 feet AGL. An airplane (of comparable size) descends slower after an engine failure and the crew has more time to look for a suitable forced landing landing site.

The immediacy of the forced helicopter landing requires a multitude of clear landing sites to achieve an uneventful landing. The pilot must quickly find a suitable landing site, for although the helicopter needs less room to land (than the airplane), the space need to be relatively closer.

Thus, the pilot of a single-engine helicopter must always select routes which support the eventuality of an engine failure. This may require operations at higher altitudes to increase the area available to the pilot for selecting a potential landing zone. Additional altitude may also be selected to insure the ability to complete a 180 degree turn, into the wind, for landing. Alternately a scarcity of suitable landing sites may cause certain routes to be avoided if flight must be conducted at a certain lower altitude to avoid an overcast. In any case, it is rare to expect more than 60 seconds between engine failure and touchdown. This means the pilot must be able to see to fly to the best location and see to flare to land.

Darkness adds a substantial degree of difficulty to both the ability to see a landing site and the ability to conduct a successful autorotative landing. While pilots are aware of the added degree of difficulty, little time is spent practicing night autorotations. On the other hand, the risk and degree of difficulty probably explain why night flying operations typically produce a very small portion of the revenue developed with single-engine helicopters.

The addition of a second-engine eliminates the need for an immediate landing after a single engine failure. The risk reduction associated with the availability of a second engine has been recognized by the EMS community which appears to be shifting to twin-engine helicopters, especially for night operations.

Approached from a different perspective, the growth of the twin-engine helicopter community brings with it the pressure to increase night operations. The constraint to operations associated with the potential single-engine failure is gone and capability is up, but the need for increased utilization means there is a need to fly at night. The twin-engine helicopter costs more (per seat mile) and profitability dictates increased utilization.

HELICOPTER WORKLOAD ISSUES

General. Like airplane pilots, helicopter pilots desire to achieve adequate performance during long term flight path tracking tasks with reasonable (low) workload. If high workload (above the reasonable level) is required to achieve adequate performance, it follows that reasonable workload will not produce adequate performance; suggesting a reduced margin of safety. The margin issue is important because it is the margin which allows pilots to safely recover from blunders in flight or inadvertent encounters involving severely adverse weather. It is important to know where workload comes from and how it can be relieved.

Flying Qualities. Some helicopters are easy to fly when strong visual cues are available, but very difficult to fly during instrument conditions. Most civil helicopters can not be flown accurately (IMC) for even brief periods at speeds below 40 knots and sustained rearward flight in civil helicopters is impossible. The more the aircraft deviates from the desired flight condition, the more compensation is required. This compensation translates into workload. Improved flying qualities can be obtained by adding stability and control augmentation equipment and autopilot

functions. These improvements in turn reduce workload. This relationship between flying qualities, workload, tracking performance, and visual cues is well understood. For example, the FAA requires helicopters which are to be flown under IFR conditions to have better flying qualities (and lower workload) than required of helicopters restricted to VFR operations (Federal Aviation Regulation (FAR) Part 27, reference 12; and FAR 29, reference 13). Only recently has the impact of difficult visual conditions been considered in a formal government document, "Aeronautical Design Standard, Handling Qualities Requirements For Military Rotorcraft," (reference 14). The approach embodied in this standard is expanded in a paper on the subject of reduced visual cues (reference 15).

Short Term Situational Awareness. Cockpit displays provide some information and the view through the windscreens and side windows provides the remaining cues. The better the ability to see outside and the better the aircraft is instrumented, the lower the workload.

Long Term Situational Awareness. The pilot also needs information to use in navigating from one place to another. The more and better this information is presented, the lower the workload. The long term also requires the pilot to look for traffic, obstructions, and weather. The advent of GPS based area navigation systems will greatly enhance the navigation of rotorcraft in the low airspace. This capability also opens up an opportunity for the helicopter to operate in now unused airspace just above 1200 feet AGL.

Communications. The need to communicate always increases cockpit workload and sometimes is the straw that precipitates an accident when the pilot is already overloaded. Communications with air traffic control system continues to be a problem requiring advanced technology or special procedures for rotorcraft.

Miscellaneous Cockpit Duties. The pilot must also monitor fuel levels, engine health, and radio traffic. From time-to-time there are requirements to deal with malfunctions and occasionally the pilot must deal with emergencies. All involve workload, even if the pilot does nothing more than monitor the trend of an engine and transmission. These duties are often deferred in the presence of high workload situations and this deferred pilot performance can result in missed malfunctions which turn into emergencies.

Workload Relief. Workload relief comes in many forms. When a single pilot is given a co-pilot, the co-pilot provides workload relief. The inclusion of an autopilot, a precision navigation system or an advanced electronic display system can provide workload relief. Sometimes workload relief systems results in more precision, sometimes they reduce fatigue. On occasions, workload systems allow crews to deal more effectively with an adverse event: bad weather, aircraft failures, etc. In all demanding flight situations, workload relief will contribute to an increase safety of flight. On the other-hand, automation may add workload and the potential for error.

SINGLE PILOT OPERATIONS

The vast majority of all civil helicopter operations are conducted single pilot, and so most civil helicopter accidents occur during single pilot operations. A single pilot experiences greater stress and be more likely to err when something goes wrong, unless adequate workload relief is provided.

A pilot who learns to fly during single pilot operations, learns from experience. Such a pilot does not have the opportunity to learn by watching a more experienced pilot but often learns through rational experimentation; expanding the pilot-machine envelope a little at a time. A single pilot learns from personal experiences. This accumulation of experience may include many near disasters which have been salvaged through the application of substantial compensatory piloting skills. In effect, the experienced pilot who has had no accidents, probably has developed an understanding of the aircraft and pilot-aircraft limits through a keen sense of observation and an ability to recall empirical data. On the other hand, the accident free pilot may have employed superior judgement to avoid situations requiring superior skill.

TOTAL UNDERSTANDING

A total understanding of rotorcraft and the operations they are applied to is essential to the development of meaningful improvements. The preceding is but a brief introduction to characteristics involved.

SECTION 3

VISUAL CHARACTERISTICS REVIEWED

INTRODUCTION

This study focused upon the task of civil helicopter pilots during visual operations and was particularly concerned with identification of those factors which contributed in any way to helicopter accidents involving collisions with obstructions.

DIFFICULT VISUAL CONDITIONS DEFINED

The study discovered that a number of accidents occurred under visual conditions which are best characterized as "difficult." That is, a degree of difficulty was introduced as the result of darkness, precipitation, dust, smoke, etc. In recognition of this situation, it has been useful to coin a new phrase to help refer to the conditions in which helicopter pilots are often involved. "Difficult visual conditions" (DVC) was selected as the term to use when referring to visual flight conducted under situations where the aircraft is being flown in VMC, but one or more vision degrading factors have introduced a significant degree of difficulty. It is important to recognize that difficult visual conditions are not in and of themselves dangerous. Yet dangerous flight operations can evolve if the crew attempts to exceed their capabilities or the capabilities of their aircraft while operating in DVC.

NEED FOR VISUAL CUES

In simple terms, the need to see is dependent upon the objectives of the flight and the ease with which the pilot can command the aircraft. If the task is visual and brings the aircraft very close to the terrain or obstructions, the aircraft must be easy to control and the visual cues must be strong. If the aircraft is difficult to fly, the visual cues must be strong and the aircraft must be flown higher above the terrain to retain the same level of flight safety (as relates to obstruction avoidance). When there are few useful cues and the aircraft is difficult to fly the altitude clearance must be increased and/or the speed suitable reduced to retain a reasonable level of safety.

Slow Speed Flight. In the case of a helicopter, the aircraft can be controlled somewhat like an airplane at high forward speeds, but when the aircraft slows below about 40 knots airspeed, three things happen: (1) the aircraft typically becomes less stable and the control cross-coupling becomes more noticeable, (2) the forces and accelerations which normally cue the pilot are substantially diminished and may be lost in cockpit vibration, and (3) the power management effort often becomes substantial.

Finally, if the aircraft is inadvertently flown into modest rearward flight, control can become increasingly difficult and perhaps result in catastrophic events. The aircraft will respond to a positive static directional stability (yawing moment) and repeatedly depart the desired heading to weather cock into the relative air mass. Similarly, the

horizontal stabilizer will provide an upsetting pitching moment. That is, the aircraft will (if briefly unattended) tend to depart from the selected pitch attitude. Therefore, rearward flight introduces a situation which the pilot interprets as an instability in pitch and yaw. Both parameters will typically exhibit periodic divergences; the time to double amplitude depending upon the rearward speed of the aircraft.

High Speed Flight. In the civil helicopter community, forward flight objectives are typically undertaken at altitudes of 500 above ground level (AGL) feet or greater and speeds of 60 knots or greater. At this altitude, the pilot needs a strong horizon line and if conducting a contact navigation task, surface cues are required.

As the operating altitude is decreased, the forward speed of the aircraft is normally reduced to allow the aircraft to follow the contours of the terrain and to prepare for landing.

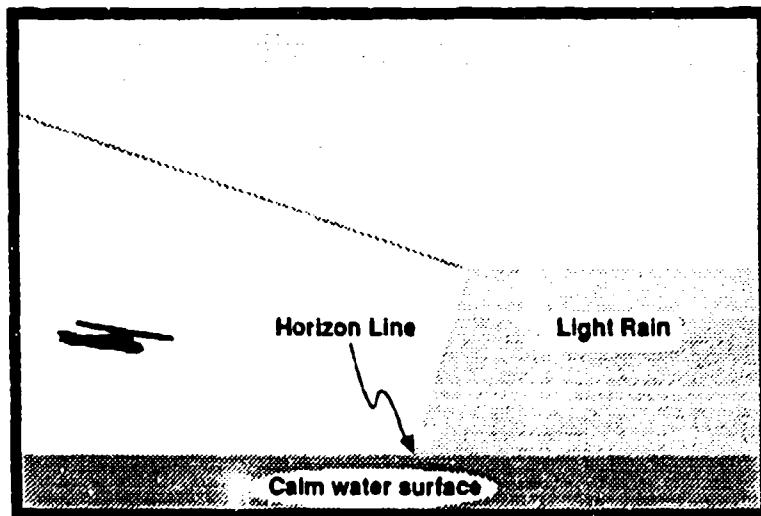


FIGURE 3-1. THE SURFACE PROVIDES THE HORIZON LINE REFERENCE

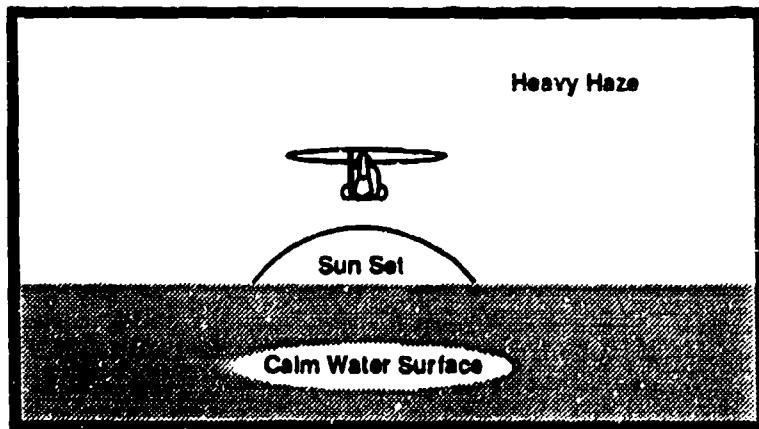


FIGURE 3-2. FLYING INTO A RISING OR SETTING SUN

Hover - Landing. Landings are typically preceded by hovers at or near zero ground speed. The precision descent to a landing and hover in a confined area presents one of the most demanding piloting tasks. It is here that the quality and quantity of cues is needed most.

Thus, the up and away flying qualities are relatively good and the piloting task is relatively relaxed if the altitude above the ground is adequate. In contrast, slow speed flight brings with it a general degradation in flying qualities and the stress which accompanies near terrain operations.

DAY OPERATIONS

As mentioned earlier, the presence of fog, haze, dust, blowing snow, falling snow, and rain can all interfere with a pilot's ability to visualize a horizon and see obstructions. Figure 3-1 reminds the reader that the sky, forward view, and terrain can all appear to have about the same coloring or texture. When this happens, there is little for a pilot to use as a horizon reference, and it becomes difficult to estimate the available visual range.

The problems associated with smoke haze, dust, etc., are all exacerbated by the need to fly into a bright sun (see figure 3-2). Only the prudential rule of common sense (or good judgement) will preclude such operations. That is, no regulations specifically preclude such operations and none are required.

When day operations are conducted above all terrain features, the pilot does not need to see the terrain near the aircraft to achieve reasonably good flight path control. The pilot can select a constant power setting, use the longitudinal control to hold altitude, and accept the airspeed that results. A landmark on the horizon will normally suffice for heading reference and a horizon line (of some sort) will support pitch and roll attitude management.

As flight nears the terrain, the altitude control strategy is redefined. The pilot no longer maintains a constant pressure altitude, but selects a path which considers the proximity of the earth surface and the obstructions. If heading is held constant, the pressure altitude must be high enough to insure safe vertical and horizontal separation from obstructions. There is a modest increase in need for precision, but this is more than offset by the increased number of quality visual cue sources which are available as a result of the decrease in visual slant range which accompanies the descent (to say 500 feet AGL).

At lower altitudes, the aircraft must be flown over or around macro terrain features. This requires constant visual contact with the surface. It logically follows that the closer the aircraft is flown to the surface, the slower it must be flown. At some altitude, it is either not possible or not desirable to fly over macro terrain features and the aircraft is flown so as to follow the folds of the terrain, flying around some obstructions and over others.

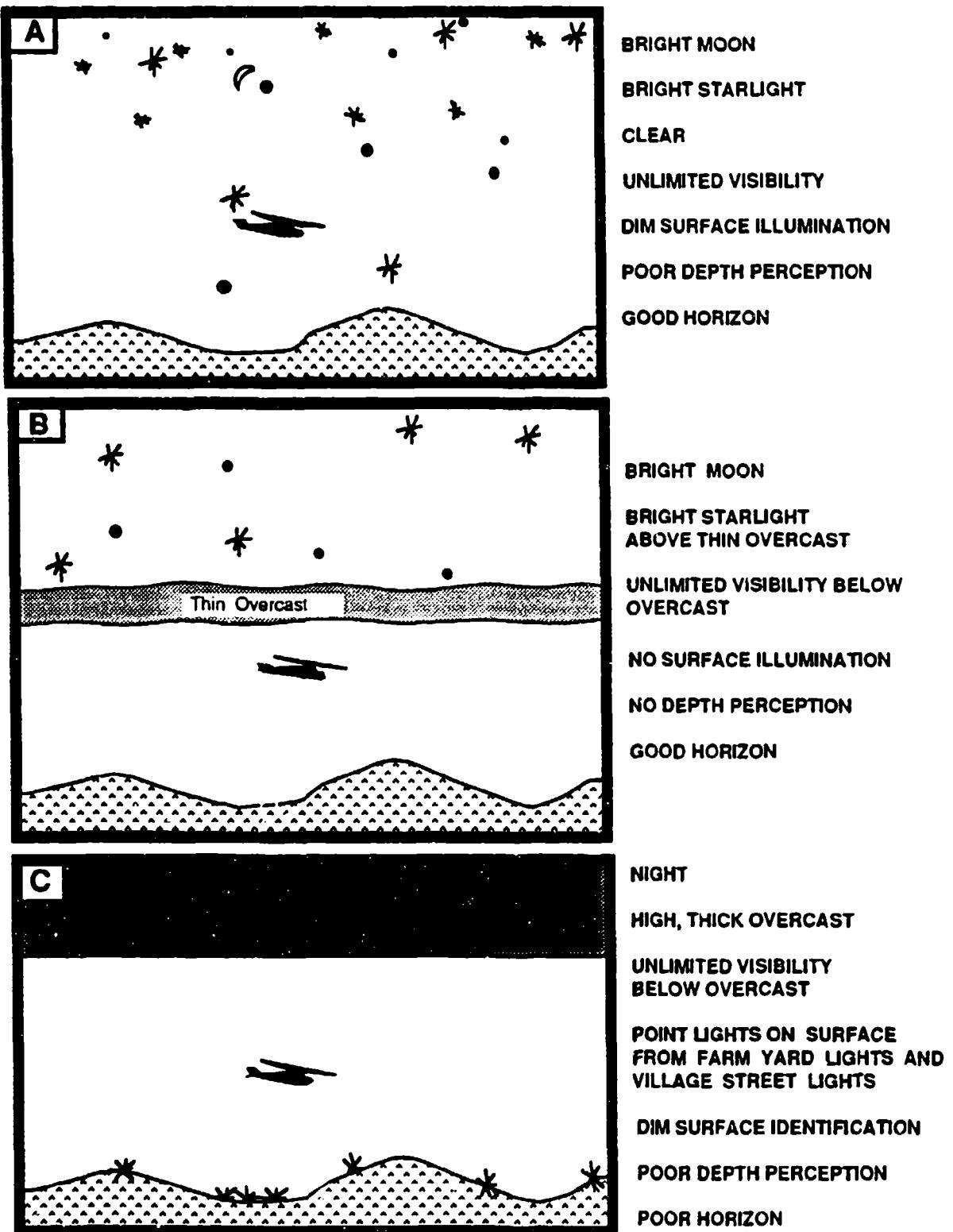


FIGURE 3-3. A SELECTION OF GOOD VISUAL CUE ENVIRONMENTS FOR CRUISE EN ROUTE

When a pilot attempts to fly at a constant altitude in a haze over a level surface, the surface will tend to disappear at some range from the pilot's eye. When the pilot looks straight ahead, the surface seems to disappear along a line which stretches from right to left, perpendicular to the flight path. The pilot sees this line over the instrument panel glare shield.

As visibility decreases, this horizon line will eventually disappear below the instrument panel. Descending to a lower altitude allows the pilot to regain this visual reference. Under some conditions the aircraft must be flown slower to avoid overflying the pilot's visibility (and the dynamic ability of the aircraft to follow terrain features). Once the aircraft is very low and very slow, the need for visual range is significantly diminished. If the surrounding cues are strong, a visual range of roughly 500 feet is normally adequate to hover, as long as the aircraft is at or near zero ground speed. If the aircraft continues to move forward, substantially more visibility is required to allow a pilot to see and stop to avoid an obstructions.

One can estimate the need for slow speed visual range by computing the distance which will be covered in the period of time required to detect, recognize and stop from a very slow speed, say 20 knots ground speed. [For example, assume that it takes 5 seconds to detect and recognize a need to stop. --- The 5 seconds considers the need for eyes in and eyes out task accomplishment. --- The distance covered in 5 seconds at 20 knots is roughly 170 feet. The distance required to decelerate is roughly 170 feet and takes about 10 seconds. The total is 340 feet. A visual range of 500 feet would allow a pilot to stop 160 feet short of the obstruction. All of this is reasonable if a strong visual cue environment exists within the near field of view. A strong visual cue environment would include trees, rocks, bushes, buildings, runways, heliports, lights, etc.]

NIGHT OPERATIONS

The term "visual flight" refers to flight conducted under VMC. This term does not specifically include consideration of lighting. Lighting is not a meteorological condition and therefore is not a factor in defining VMC or IMC. Flight during darkness has long been appreciated by the FAA for civil night operations and is addressed in PART 91 of the FARs (reference 16). Lighting during EMS operations is additionally covered by FAA Advisory Circular No. 135-14, "Emergency Medical Services/Helicopter EMS/H" (reference 3).

Figures 3-3 and 3-4 illustrate the variation in the night lighting environment which civil helicopter pilots may encounter. The range in ambient lighting levels, visibility, and surface lighting is substantial but these figures tend to present a spectrum which is instructive when considering night visual operations.

Frame A (fig. 3-3) illustrates the beautiful night, the kind every pilot hopes for: A vivid horizon line, bright moon, and star light with sufficient surface illumination to see lakes, and surface shades of grey produced by the contrast of woods, grain fields and plowed fields. If the wind blows, white caps and wind streaks are visible.

In frame B (fig. 3-3), a thin overcast provides a fluorescent-like canopy with a sharp and omnipresent horizon line (that is the horizon line is present during a 360 degree turn, and this is important during turning flight). While there are no surface point lights, the surface is faintly visible.

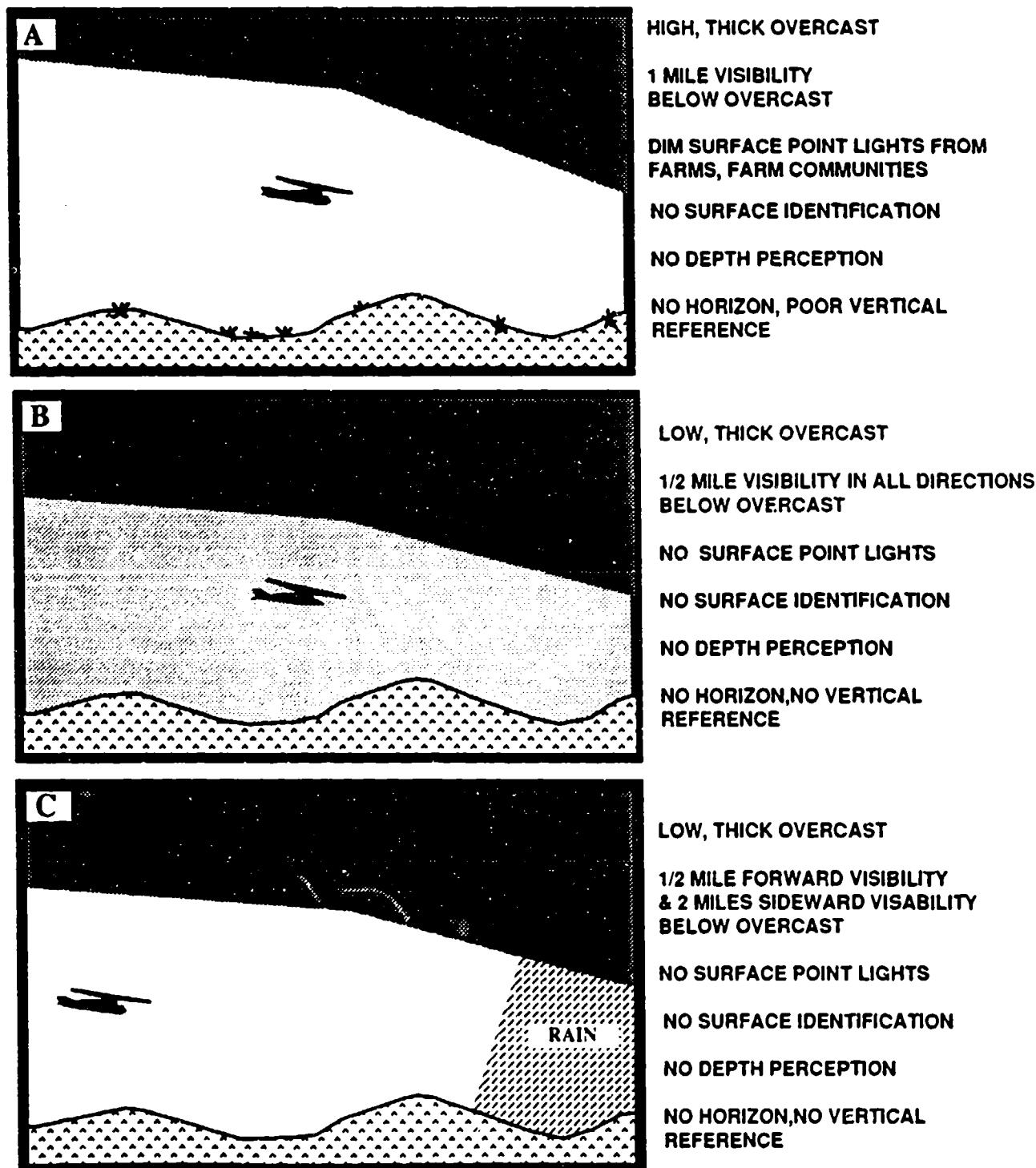


FIGURE 3-4. A SELECTION OF POOR VISUAL CUE ENVIRONMENTS FOR CRUISE EN ROUTE

In frame C (fig. 3-3), the surface is defined by point lights. These surface lights disappear in the distance due to the curvature of the earth or rising terrain (ridge or mountain range) and establish the horizon line (there is no other horizon).

The night environment continues to deteriorate in figure 3-4. The pilot of an aircraft flying at cruise speed under these increasingly difficult conditions is increasingly required to reference cockpit instrumentation to achieve the desired flight path control accuracy. This is true even though the aircraft is still operating in clear air. Even if the measured visibility is 100 miles, the lack of a horizon and the lack of any surface lighting causes the pilot to operate under conditions which are more difficult than many day IMC-IFR operations in an overcast.

Night flight is more difficult for at least two reasons. First, the pilot must use cockpit lighting, drop lights, or flash lights to achieve cockpit illumination which is always inferior to the illumination available naturally during daytime operations. Second, the pilot must ensure safe separation from other visual traffic and at some point the pilot must locate and identify a place to land (at a minimum). This second task can be complicated by reflections in the windscreens. A pilot can concentrate on instrument flight when operating under IFR, but when operating under the difficult visual conditions defined above (as night flying over an open sea) the pilot must accomplish: (1) the instrument flight task, (2) visual separation, and (3) navigation tasks.

Visual operation can be made more difficult by the introduction of illusions. For example, on a very dark, cueless night a single aircraft flying across the pilot's field of view can introduce a powerful illusion of turning.

Experience has shown that the lower a helicopter is flown over water, the better flying qualities it must have. The lack of visual cues and the proximity of the surface means the pilot must strictly control the altitude to avoid flying into the water. There is no civil requirement to fly at this low an altitude but the example does serve to illustrate the need to enhance the cockpit displays and minimize the pilot's effort to fly, if the pilot is expected to accomplish any other en route duties, like look out for other aircraft or change heading. This requirement to fly low over water was the driving force behind the development of stability augmentation for the SH-34G helicopter, followed by the development of automatic approach to hover and automatic hover, automatic flight control systems (AFCS), for the SH-34J. These developments matured into operational systems 30 years ago and are now found on the SH-3 and SH-60 model helicopters. Thus, the ability to fly fast and precisely under difficult visual conditions is not new and the means to accomplish this task are well understood and available.

The term "difficult visual conditions" treats a complex mix of factors, including, lighting, weather, and details of the task. The task is important because it contributes to the definition of a pilot's need for cues. The equipment on the aircraft, or lack of equipment, impacts the performance a pilot can achieve with or without cues. If the

pilot can not see anything, the task must either be so relaxed that there is no need for cues or the aircraft must be so highly automated that there is no need for cues.

The use of lighting and electronic means to develop visual cues should probably be included in the definition of operations under difficult visual conditions. First, civil operators are expected to employ external lighting (e.g., landing lights, floods or spotlights) to establish visual cues during certain low altitude operations such as takeoffs, hovers, and landings. Electronic means may be found suitable for augmenting external lighting, but such a finding is beyond the scope of this investigation.

More recently, military crews use night vision goggles (NVGs) and/or forward looking infrared (FLIR) to improve the visual cues at night. Improved flying qualities and automated flight path control are employed to accommodate the remaining need to reduce pilot compensatory workload caused by low altitude operations to a tolerable level and achieve adequate performance. But much like the human eye, these sensors are subject to limits involving minimum illumination or heat gradients and the crews must learn to interpret the related presentations as explained in reference 37, TC 1-204, "Night Flight, Techniques and Procedures."

INTRODUCTION TO HELICOPTER VISIBILITY CHARACTERISTICS

Primary Viewing. To review, figure 3-5 illustrates the primary lines of sight (LOS) used by helicopter pilots. Line A depicts the lower edge of the conventional forward field of view. Line B reminds us that additional depression in LOS can typically be obtained by leaning to one side and looking around the instrument panel. The view through the feet is extremely important during hover operations but is also important during cruise because it provides peripheral cues of pitch rate and speed (among others). Similarly peripheral roll attitude and roll rate cues come from the side window. Overhead panels allow the pilot to look up for other aircraft and look into steep turns, but peripheral cueing through the overhead is essentially nonexistent.

Visibility From Small Helicopter Cockpits. Small helicopters usually provide a pilot with the least obstructed view. The instruments are generally located on a pedestal centered between and forward of the pilot seats. This type of pedestal may contain some flight instruments (air speed, pressure altitude, attitude, rotor tachometer, and engine instruments), but it is not meant to support instrument flight. The pilot can easily see straight ahead and through the opposite side of the cockpit.

Some older aircraft have no instrument panel in front of the pilot and the pilot is able to look out through a large clear windscreens, uncluttered by any cockpit fixture. This lack of a visual fuselage attitude reference can be very bothersome, especially at altitude and during poor visual conditions. Pilots have even been known to draw horizontal lines on the canopy of such aircraft to increase precision and decrease workload.

Instrument Panel Impediment to Forward Visibility. The addition of a full instrument panel, capable of supporting instrument flight (but possibly not certified for instrument flight) tends to block the pilots view for VMC operations. In some installations, the IFR instrument panel may extend across one side of the cockpit and not the other, with the effect of providing some relative increase in ability to see, in comparison to the full span panel which extends from one side of the cockpit to the other. The smaller the aircraft, the more difficult it is to install an instrument panel without obstructing the pilots forward view.

Large Helicopters, Single Pilot. As helicopter size increases from the smallest practical vehicle size, it becomes easier to install an adequate instrument panel. It is generally correct to assume that, as the gross weight of a helicopter increases through about 5,000 pounds, it becomes very easy to install a fully equipped instrument panel in a way which permits excellent simultaneous forward and downward visibility.

When aircraft becomes very large (over 30,000 pounds), the structure ahead and to the side of the pilots station may introduce new and different impediments to the pilot's ability to see out. Most importantly, the dimensions of a large cockpits can restrict the cross cockpit visibility of a single pilot.

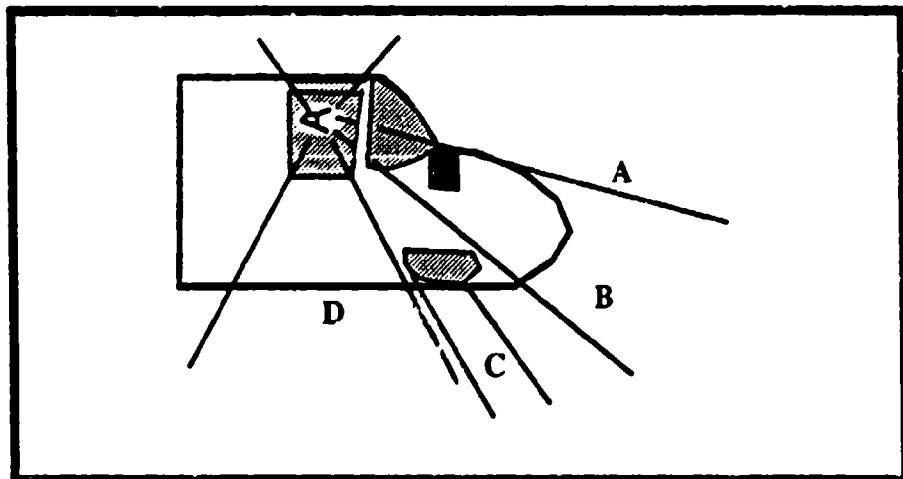


FIGURE 3-5. PILOT VISIBILITY DOWN AND TO THE RIGHT FROM THE RIGHT SEAT

Perception of Roll Attitude. Pilots often use the top of the instrument panel to establish a wings level attitude with the external horizon reference. If the instrument panel is angled relative to true wings level, the pilot may or may not be influenced, depending upon his background and familiarity with the aircraft model. If there is no instrument panel, the pilot may not have any aircraft structure in his/her LOS against which to judge wings level. This is normally a minor problem but can contribute to uncoordinated flight, uneasiness, and fatigue when operating with diminished external cues. This characteristic and other similar cockpit (human factors) issues are discussed in reference 16 and reference 17, "Cockpit Integration From a Pilot's Point of View."

As the speed increases above that for maximum endurance, most helicopters fly more and more nose down. In some aircraft, the nose down attitude becomes substantial. When this occurs, some pilots may unconsciously use the top of the windscreen to judge roll attitude, especially when a strong horizon line appears in this location. The black silhouette of a mountain range or a cloud formation may provide a suitable horizon cue for cross reference to the top of the windscreen.

Limited Visibility Should Limit Airspeed. Part 91 of the FARs (reference 17) stipulates that helicopter pilots must fly at a speed which permits the pilot to see and avoid other aircraft and obstructions. Part 135 (reference 18) expands upon this visibility criteria by establishing a 1/2 NM minimum for daytime visibility when operating in uncontrolled airspace. Considering the geometry of the typical helicopter, and the eye reference point of a given helicopter, what do these requirements mean? The following is provided as a quick look, introduction to this subject.

Pilots can normally expect to have a clear look-down angle over the nose of at least 15 degrees during forward flight. If this is the case and the pilot maintains 500 feet AGL over a level surface, surface features approaching the aircraft will disappear from the pilot's view (under the nose) at a point about 2,000 feet ahead of the aircraft. When forward visibility is 1/2 NM, surface features are exposed to the pilot's field-of-view for about 1,000 feet (see figure 3-6). This 1,000 foot deep view of the terrain ahead should be consistently available over a 60 to 90 degree horizontal field of regard. On first analysis, this seems to provide a reasonable daylight field-of-view to sustain VFR operations when operating at speed up to but not greater than 100 knots ground speed.

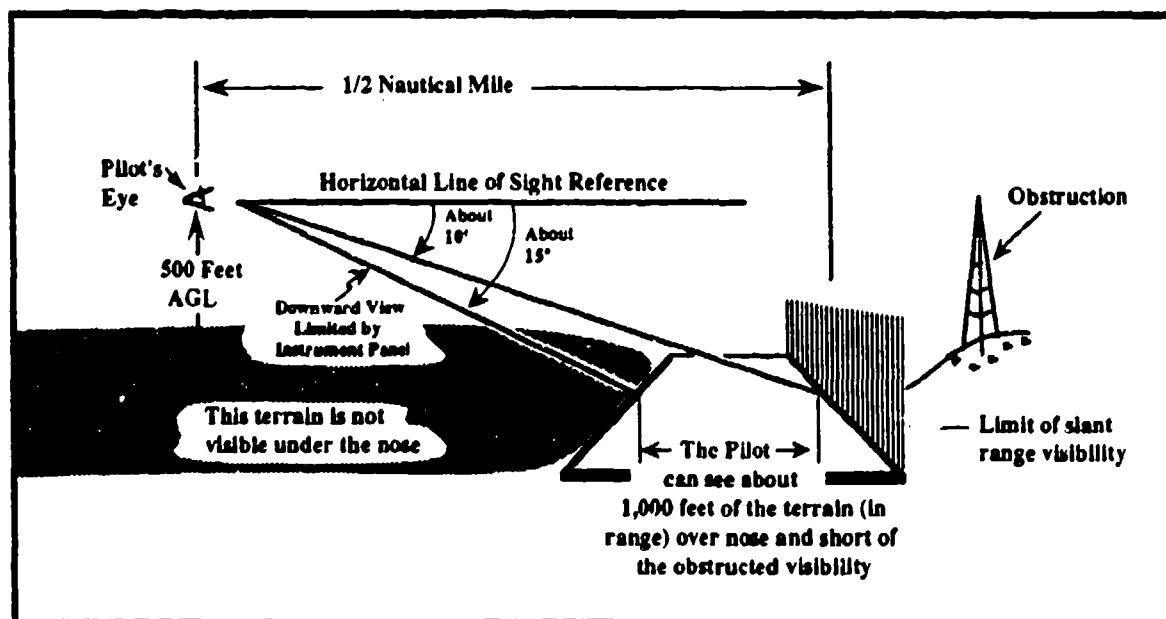


FIGURE 3-6: A CHARACTERIZATION OF THE FACTORS INVOLVED IN SEE-AND-AVOID HELICOPTER OPERATIONS

To understand why it makes sense to fly no faster than 100 knots at 500 feet, first consider the need to see and recognize the obstruction to be avoided. Assume, for the sake of a first look analysis, that 5 seconds is adequate for all pilots to see and recognize their need to maneuver to avoid an obstruction. Further assume that a straight ahead deceleration will yield a conservative (operationally safe) avoidance maneuver. The ability to stop short of an obstruction seems to be an appropriate and adequately conservative (first look) performance objective. That is, it appears to be axiomatic that if you can stop short of an obstruction, you can avoid it through a number of alternative maneuvers as well. Reference 19 addresses maneuvers to avoid obstructions and the preceding is consistent with its findings, as adapted to visual civil helicopter operations. At 100 knots, the aircraft will travel about 800 or 900 feet in 5 seconds. If one assumes that all pilots will take the full 5 seconds to look-up, see and recognize the object before starting the maneuver, the deceleration must be completed in not more than 2,100 feet (3,000 feet visual range less 900 feet to see and react equals 2,100 feet).

A typical straight-ahead stop-to-avoid maneuver will require the pilot to flare roughly 12 degrees (nose up attitude change). Any more than this and the pilot will run the risk of loosing visual contact with the obstruction. This flare should produce an average deceleration of roughly 7 feet per second-squared and stop the aircraft in about 2,000 feet, just short of the obstruction. At the alternate speed of 120 knots, the entire 3,000 feet (1/2 NM) of visual is required to achieve the stop, leaving no time to see and recognize an obstruction. Conversely, at 60 knots, the pilot has 10 seconds to detect an obstruction and need not flare more than 5 degrees to stop well short of an obstruction in about 30 seconds. The 5 degree flare is probably the most paying passengers will tolerate.

In summary, each aircraft has a unique look-down characteristic which typically varies with airspeed, gross weight, and center of gravity. Pilots can determine the nature of these characteristics as they apply to their aircraft (and the way they adjust their seat and eye reference point location) and use this knowledge in combination with their observed height above the ground, to estimate the available forward visibility (and the maximum usable airspeed). This is the only way available today for a pilot to judge the en route visibility and chose a safe speed for the existing condition. Nowhere in the literature is there a discussion such as has been presented here for an inquisitive pilot to read and use in an effort to comply with FAA regulations and enhance safety. Future helicopter handbooks could remedy this situation and encourage pilots to analyze their operational situation and enhance flight safety through expanded awareness.

ViSUAL SEGMENT OF AN INSTRUMENT APPROACH

Future "helicopter only" approaches may include consideration of the helicopter's vertical and lateral, slow speed agility in terms of obstruction detection and avoidance. It is therefore appropriate to include the final visual segment of the helicopter instrument approaches in this and future studies of obstruction avoidance.

By definition, the visual cue environment associated with IMC will not support contact-visual flight and the presence of IMC requires the pilot to depend entirely on cockpit instrumentation, but at decision height (DH) on an IMC precision approach, the pilot must establish visual contact with the airport environment or execute a missed approach. The pilot is visual (operating VMC) when the airport environment is in sight and the pilot is able to see the airport well enough to complete a safe landing. In some cases, it is even permissible to cancel the existing flight plan and continue VFR.

The fact that the pilot enters a VMC environment does not mean that the pilot should complete the visual segment of the approach without cross referencing the cockpit instrumentation. But it does infer that the pilot can use a combination of cue sources, scanning inside and outside to make the best use of the available external cues and cockpit instrumentation and improve the precision of the touchdown point as well as final runway or heliport alignment. Even difficult visual conditions are acceptable for this purpose.

The airspace on a precision (instrument) approach is known to be clear of obstructions and the pilot should not need to maneuver to avoid obstructions or other aircraft. To avoid obstructions, the aircraft must only be agile enough to remain in the volume of clear airspace protected for the instrument approach. That is, the visual cues must be adequate to support the final navigation and flight path management needs of the pilot. This is an interesting unique situation and will be important as the concept of difficult visual conditions and other principles of obstruction avoidance are developed and applied to future helicopter approaches and en route operations. In a sense, the visual segment of the current instrument approach establishes the precedence for many of the concepts and procedures tied to the concept of "difficult visual conditions."

SECTION 4

ANALYSIS OF COMPOSITE PROFILES

This section reviews the process used to reconstruct the composite flight profiles that collectively cover the operations of significance to the public's need for rotorcraft transportation (section 2) and the environment within the low airspace of the NAS (as explored in section 3).

Profiles were reconstructed from factual knowledge obtained as the result of expert analysis of over 150 of the most germane helicopter accidents available. Most of these profiles are composites in that each reflects the common characteristics of a number of accidents. Each composite is described, analyzed, and discussed to illustrate lessons learned and needs for change.

TWO TYPES OF ACCIDENTS

All of the accidents reviewed fell into two general categories. The first group was felt to be mission oriented; the second group did not involve a clear need to conduct the maneuver which led to the accident. This second group then appeared to involve reckless and unnecessary operations and most were judged to fall outside of the scope of this program.

Mission-Driven Accidents. Some accidents were mission driven; the pilot simply attempted to fly the aircraft to a point, or along a path at an altitude which would allow the pilot or embarked customer (passenger) to achieve the objective of the flight. The pilot did not conduct outrageous maneuvers or otherwise intentionally conduct the flight in a reckless way. The pilot did appear to make a mistake. In some cases the pilot appeared to used poor technique or judgment. These were "apparent pilot error" situations. It is impossible to know exactly what happened in many cases, thus the use was "apparent." In other cases the pilot appears to have been the victim of circumstances. This alternative includes illusions, acts of others, and/or apparent acts of God. The following are typical examples of mission driven accidents:

- **Failed Reconnaissance.** Conducted reconnaissance, but didn't see wire.
- **Mission Change.** Pilot altered course abruptly, at the request of customer, and flew into a hazardous environment without an adequate reconnaissance. Aircraft strikes wire that can not be detected by the pilot. (Sometimes the layout of the cockpit and the direction of the turn combine to preclude an adequate view of the obstruction.)
- **Power.** The pilot flew unnecessarily low over a ridge. To cross at a higher altitude would have required more time to climb because of the modest margin of power available for climb. (Had the pilot used good judgment to delay the crossing until climbing higher, or if the pilot had more power available, the accident would not have happened.)

Reckless and Unnecessary Operations. There are other accidents which involve considerable poor judgment, extremely poor piloting techniques, or reckless disregard for flight safety. For example, if a pilot returning from a mission elects to fly below the bank of a small river, 10 to 20 feet above the water, and the pilot's only justification for following this profile is the pilot's personal desire, the flight represents reckless operations and a willful and flagrant disregard for flight safety. Alternately, the pilot may be grossly under trained, or otherwise under equipped for safe flight operations. In summary this group includes:

- flight by unqualified crew (e.g., operating IMC without instrument training),
- flight by a crew "under the influence,"
- flight into known severe weather or adverse visual conditions in an aircraft not adequately equipped, and
- intentional, extended operations deep in an obstruction rich environment.

Some of these accidents involve useful data because they contain characteristics which have parallels in mission driven accidents. For this reason, an effort was made to search for these useful facts and incorporate them into an appropriate composite profile.

FORMAT

Sections 5 through 11 address families of composite accidents which have been found worthy of analysis. Each section considers one to five composite flight profiles.

Overview. An overview is presented at the beginning of each section to introduce the common aspects of the associated profiles.

Scenario. A brief scenario, supported by graphics, is included for each profile. Each scenario is numbered based upon the section and the order of presentation within the section. For example, scenario 7B is the second scenario in section 7.

Discussion and Analysis. Each scenario is discussed. Pertinent facts are reported and briefly analyzed to develop an understanding of how helicopters and helicopter pilots fly, and how the pilots think. What constraints are in the back of their minds? What are the rule-of-thumb performance guides? What illusions are they subject to? Has their training been inadequate?

Observations and Findings. Observations, findings and suggestions are collected for all of the scenarios in each section. These summaries are found at the end of each section.

SECTION 5

TAKEOFF INTO OBSERVED WIRES

This study found a significant number of incidents involving flight into objects which pilots were aware of, and often could see, but for one reason or another did not avoid. These apparently avoidable accidents are easily disparaged as being stupid pilot errors. But conversely, there is possibility that an analysis of some of these accidents could be very productive. This appears to be true in the case of many takeoff accidents, day and night.

Wire strikes figured predominantly in this category of accident but ground transportation vehicles, radio antenna, trees, and small buildings are also on the list of objects struck (see reference 20 for a summary of recent experience recorded on and about heliports and airports). The initial review of accidents conducted in support of this study also discovered that wind conditions were reported to have played some part in many of these apparently avoidable accidents (a similar finding was reported in reference 20). The analysis of the trajectories and initial condition involved in still other accidents lead to the conclusion that wind had probably been a contributing factor although this fact had eluded the accident investigation team. In summary, many of these "wind" accidents involved takeoffs in cross winds, which ended in a ground, tree, or wire strike. Thus, this category of accidents seemed to be an excellent place to start. There is a need to understand clear air, good visibility accidents before considering the complication of difficult visual conditions.

CROSS WIND TAKEOFF INTO WIRE SCENARIO (5A)

The pilot entered his aircraft to conduct a takeoff under temperature and gross weight conditions which were within normal operating limits as determined by a power margin check conducted during a low in ground effect (IGE) hover. The pilot proceeded to depart straight ahead with the intent of flying over wires which lay across the departure path. This was a routine maneuver accomplished daily. The aircraft struck the wires. No engine power degradation was observed. The aircraft just did not clear the obstruction (see figure 5-1) because of inadequate power for the situation.

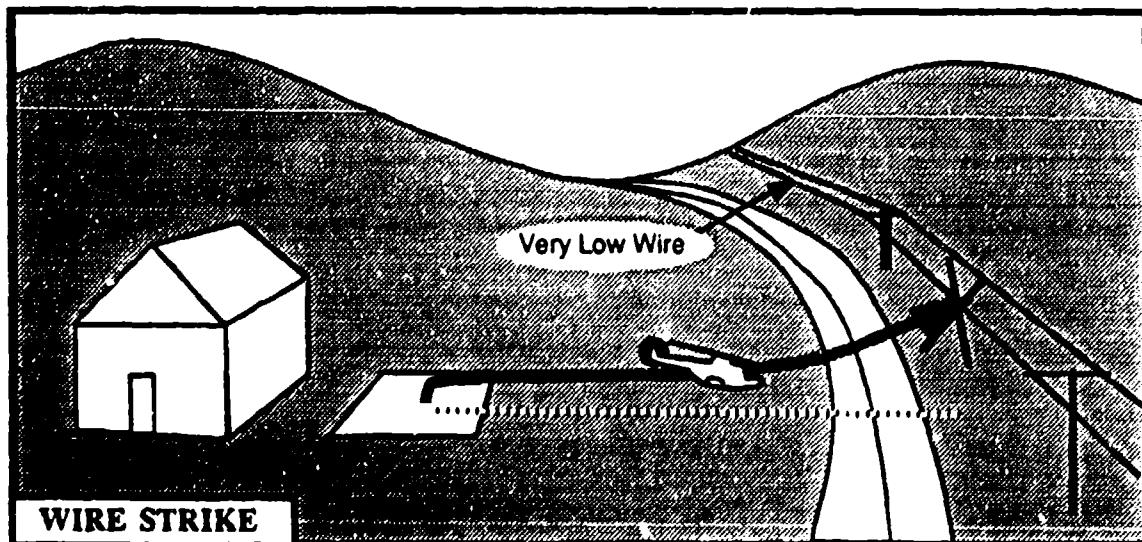


FIGURE 5-1. IGE TAKEOFF INTO WIRE AS THE RESULT OF INADEQUATE POWER AVAILABLE

ANALYSIS

Review of References. The following analysis is supported by the data and analysis contained in references 21 through 31. In review, reference 21 undertakes to define the optimal takeoff procedures for heavily loaded helicopters exiting at a confined area. The paper clearly makes an important contribution, but it does not consider the impact of cross winds. It does emphasize the need to remain deep IGE until reaching the critical rotation airspeed when it is necessary to minimize deep in ground effect until reaching the critical (best) climb speed of the takeoff distance to clear a 50 foot obstacle. It explains that if a pilot rotates the aircraft to a climb attitude too early, with inadequate airspeed, the distance to clear a 50 foot obstruction can be substantially increased and can result in an accident. This suggests that some accidents, like the one pictured in figure 5-2(B) may have been caused by failure to know or observe the guidance offered in reference 21. That is the pilot may have climbed out of ground effect before achieving the speed for best climb angle.

There are other accidents which do not appear to be explained by this error in takeoff technique. While the available accident data are lacking on many of this kind of accident, there are a sufficient number of common factors to suggest that at least some of the failed IGE running takeoffs were caused, at least in part, by a general lack of appreciation of cross wind performance characteristics. Figure 5-2 characterizes the relatively small difference between a correctly executed successful IGE running takeoff (frame A) and an unsuccessful attempt (Frame B). Assume the unsuccessful attempt involved the same hover power margin as the earlier case and the same correct application of the maximum performance (no wind) takeoff technique presented in Reference 21. What could cause the failure to climb as expected?

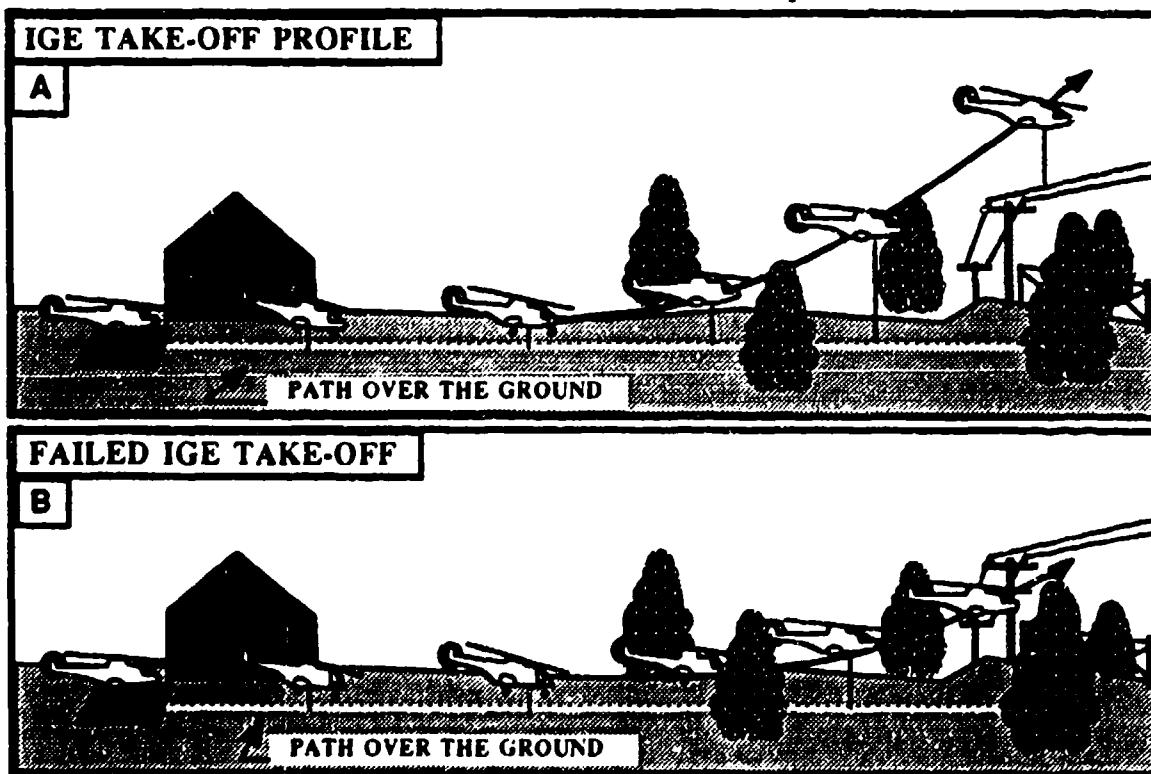


FIGURE 5-2. COMPARING IGE TAKEOFF PROFILES

Reference 22 is typical of a series of papers which has explored the impact of main rotor wake interaction with tail rotors during slow speed flight, including cross winds. But this study, like the others, does not consider the impact of cross winds on takeoff performance. Similarly, references 23, 24 and 25 contain excellent treatments of technical and operational rotorcraft takeoff performance characteristics, but these sources also fail to mention cross wind takeoff considerations, relative to clearing obstructions.

References 26 through 29 provide useful helicopter performance data, presented in context with operations from heliports. These are excellent source documents for the determination of climb trajectories and other related performance data, for no wind, head wind, and tail wind operations. But like the preceding references, these do not provide insight into the impact cross winds have on takeoff performance.

While no reference was found which treats the influence of cross winds on takeoff performance, there were a few which considered power required for level flight as a function of changing relative winds (i.e., a takeoff in a cross wind). In particular, figure 8 of reference 16, figure 5 of reference 30 and figure 17 of reference 31, all address "three dimensional power required" or "omni-directional power required"; a way of thinking about rotorcraft power required which recognizes the omni-directional flight capability of the helicopter (that is the helicopter can translate through the air mass in all directions). Figure 5-3 is a three dimensional characterization of helicopter power required for level flight which has been adapted from these references. Observe that power required is represented by a surface. It is not a two dimensional line as is normally portrayed.

The recognition of the three dimensional aspect of power required is a step in the right direction, but the concept is not supported by sufficient data or analysis to support conclusive explanations of takeoff accidents. Until suitable helicopter performance data are collected for a matrix of omni-directional wind conditions (for analysis), a completely convincing argument will not be possible. Similarly, a satisfactory analysis of cross wind takeoff performance is beyond the scope of this study, but it is a subject which can be explored in more detail during follow-on efforts.

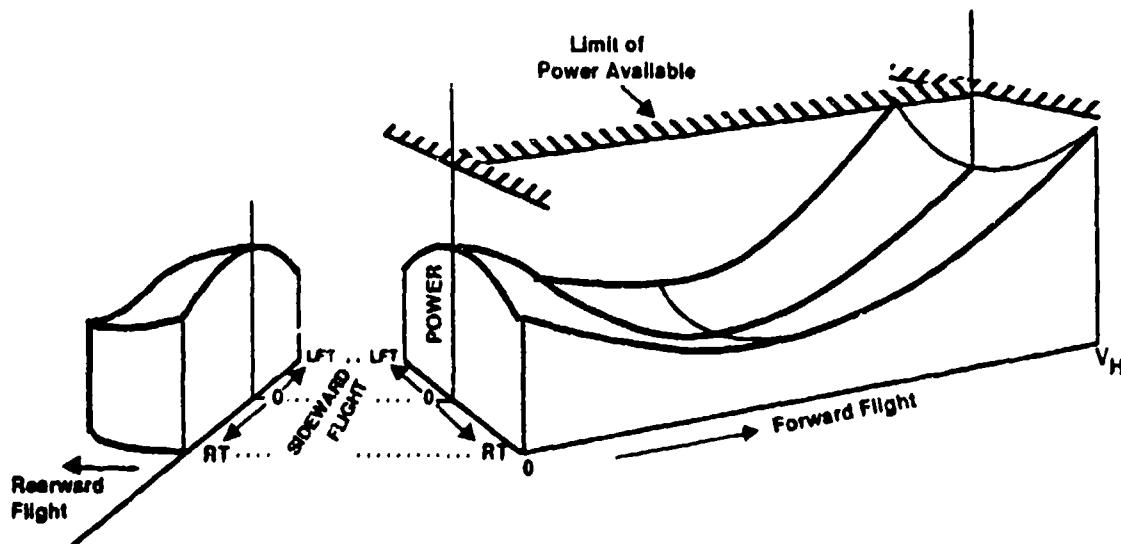


FIGURE 5-3 THREE DIMENSIONAL CHARACTERIZATION OF OMNI-DIRECTIONAL POWER REQUIRED FOR A SINGLE ROTOR HELICOPTER

Cross Wind Analysis. Many takeoffs are conducted in cross winds to accommodate the available clear space for an IGE acceleration to the critical rotation speed. Therefore, it is reasonable to conclude that several of the failed takeoffs involved cross wind performance characteristics that the pilot did not expect or understand.

For example, under normal conditions, the crew uses a low IGE hover to check the power required to hover. If the power available, above that required to hover, is sufficient (some rule-of-thumb is used), the pilot is assured that a safe takeoff is possible. That is, if the margin is some value or greater, the pilot knows from experience (and sometimes the flight manual) that a takeoff can be completed safely.

The takeoff follows a singular path regardless of the wind line. It follows a straight line over the ground (and it does not involve a crab in the presence of a cross wind). Assume that this takeoff is conducted so as to pass safely between obstructions prior to reaching the barrier obstruction which the helicopter is expected to fly over (see figure 5-4). The pilot keeps the wheels (skids) aligned with the IGE track to insure that a power loss (or pilot inattention) causing the aircraft to touch down will not result in a roll-over crash.

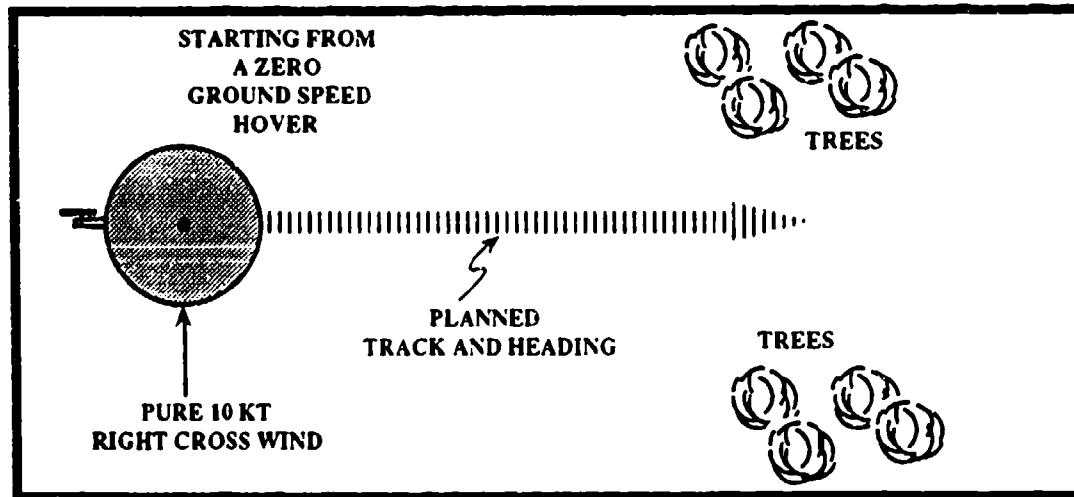


FIGURE 5-4. HIGH PERFORMANCE (IGE) TAKEOFFS ARE STRAIGHT-AHEAD

Compared to a takeoff into a head wind, a right crosswind (for U.S. manufactured helicopters) will require an unusually high proportion of the power available to be consumed by the tailrotor during the takeoff acceleration. This can become a very significant factor at about the same time as the main rotor trailing vortex interacts with the tail rotor, requiring even more power to hold heading. This increase in tailrotor power required decreases the margin of excess power available for the takeoff.

Most pilots are accustomed to no winds or light head winds, and know how the aircraft accelerates and benefits from translational lift. Pilots expect the margin of power available (to produce a climb) to increase substantially during the acceleration. This expectation is often time referenced or distance referenced. The pilot often expects things to happen within a few seconds after starting the maneuver. The pilot tends to think in terms of ground speed, the parameter the pilot can visually relate to.

The airspeed indicator may provide a useful performance cue in some aircraft but it is unreliable in most helicopters below 30 or 40 knots, especially in ground effect. In any event, ground speed provides the predominate speed cue during this maneuver, but power required is an airspeed dependent parameter and this may be a significant problem during a confined area takeoff in a cross wind.

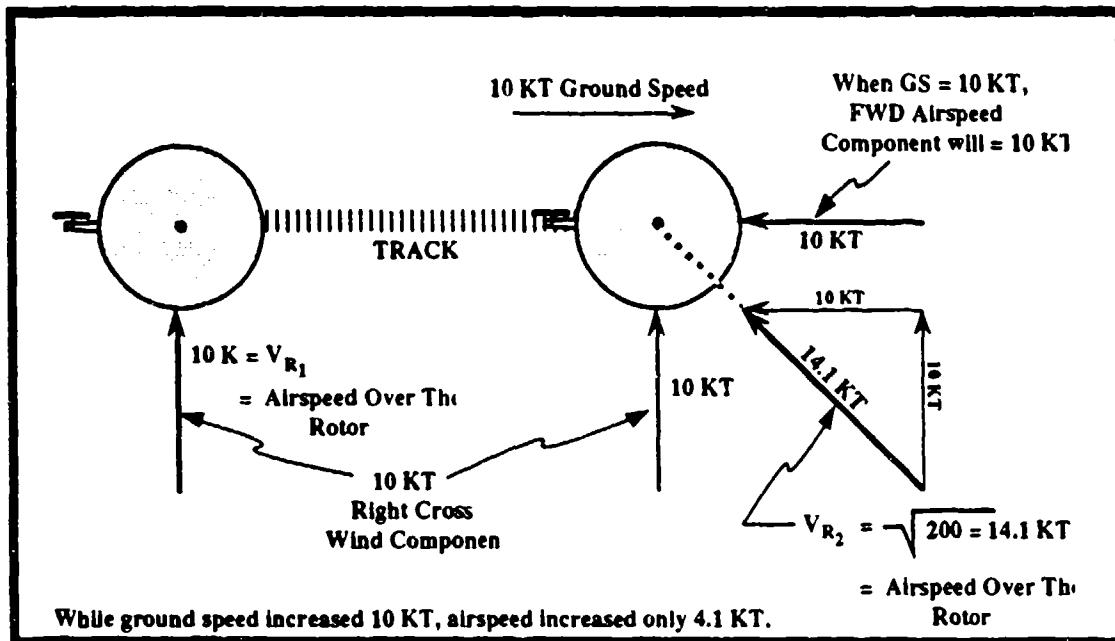


FIGURE 5-5. RELATIVE WIND CHANGE DURING TAKEOFF IN A CROSS WIND

For example, when a helicopter accelerates over the ground from 0 to 10 knots in a no-wind situation, the relative wind speed (air speed) will reach 10 knots at the same time the aircraft reaches 10 knots ground speed (GS). This will yield an incremental increase in power required for level flight and the aircraft will either accelerate faster or climb faster. Figure 5-5 includes a vector summation of the cross wind and the ground speed. It shows that a 10 knot acceleration over the ground in a 10 knot cross wind results in only 4.1 knots increase in airspeed (relative wind $V_{R_1} - V_{R_2}$). The rotor reacts to the magnitude of the relative wind vector, and it's roughly correct to say that the decrease in main rotor power required (achieved as the result of the 4.1 knot increase in airspeed) is about half of what the pilot had expected to observe as the result of increasing forward (ground speed) from 0 to 10 knots.

An additional problem may develop in the tailrotor at about the same time the aircraft reaches 10 knots ground speed. That is, the angle of the relative wind may cause the trailing vortex of the main rotor to interfere with the tailrotor. This will increase the total power required (as discussed above). This main rotor to tailrotor interference can also increase the pilot's workload in yaw control and momentarily distract the pilot, with a resultant degradation in takeoff control technique. This inattention may cause the pilot to prematurely fly up and out of low IGE flight, adding another increment of the power required and decreasing the margin for acceleration and climb.

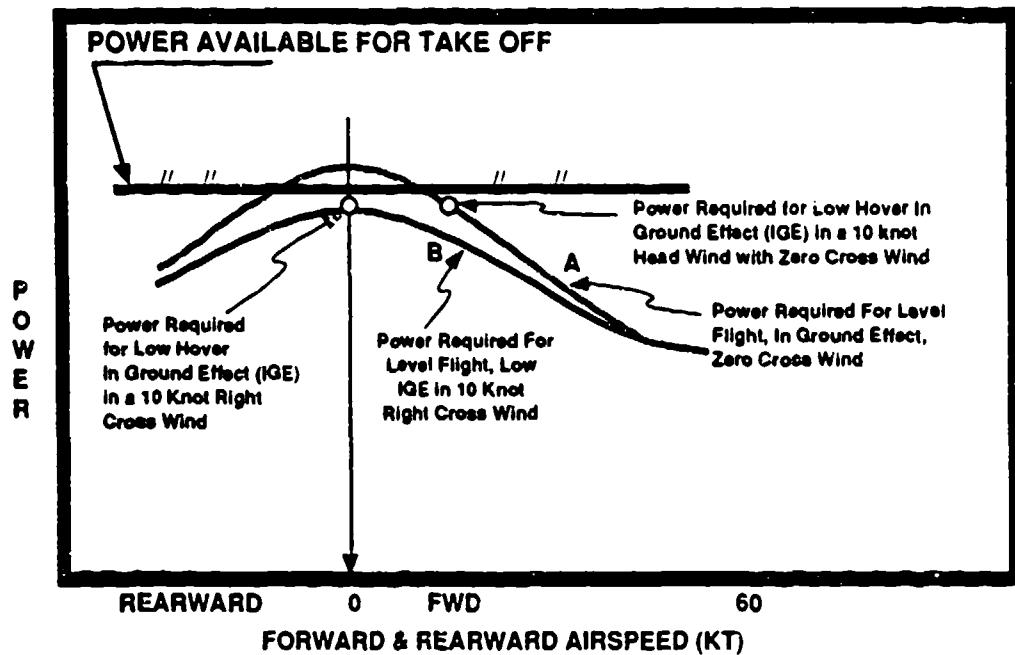


FIGURE 5-6. POWER REQUIRED IN GROUND EFFECT

Figure 5-6 holds the explanation. Compare line "A" (no cross wind component) to line "B." Look at the shape of these curves and the gap between each and the power available line. Start at the hover points. The power required line "A" drops away quickly providing an almost instant increase in power available. Line "B" drops but the rate of decrease with increasing forward speed is much, much less. The result is a much less responsive aircraft.

Translational Lift. This term is grossly misused by most helicopter pilots. It is referred to in accident reports as something that pilots either have or they don't have. It can be argued that the prevailing concept is the result of generally inadequate initial technical training for many if not most helicopter pilots. Pilots observe the way their aircraft flies and they relate this empirical performance to the sounds and vibrations they feel. The aircraft feels like "it wants to fly" about the time the aircraft starts to shake a little and the sound of rotor blade tip wake strikes the cabin (a speed of 10 to 30 knots depending on the aircraft). It is at this point that pilots have come to expect a substantial increase in power available.

The fact is, the phenomenon referred to as translational lift is the manifestation of the reduction in induced power which occurs as the translational velocity of the aircraft increases the mass flow through the rotor. This is a continuous but non-linear characteristic which starts to impact the aircraft as soon as the aircraft moves away from zero airspeed. It is a main rotor characteristic and as such is insensitive to the direction the rotor is moving; right, left, backward, or forward. It is even present during vertical climbs. The "total power required" characteristic of the helicopter is the sum of many powers, tail rotor power, the power to overcome fuselage drag, etc., some of which are very sensitive to the direction of flight. The result is a complex omni-directional power required introduced earlier and depicted in figure 5-3.

For this analysis, it is sufficient to study the curves presented in figure 5-6. Notice that the cross wind curve is much flatter than the curve drawn for the zero cross wind condition. Thus diminished slope in a cross wind is a large part of the problem. Pilots expect a much steeper slope. Restated, with increasing ground speed, they expect the power required to decrease faster than it does.

TAKEOFF FROM HELIPORT (NIGHT) WIRE STRIKE SCENARIO (5B)

From the data available, the pilot was familiar with the heliport area and was aware of a low telephone line which was under the intended departure route. Upon departure, the aircraft first climbed vertically into a low out of ground effect hover and then the pilot lowered the nose and accelerated forward. The aircraft struck the wire and crashed.

Bright lights in the near distance, along the pilot's intended route, were reported in several cases. In one case, a brightly illuminated business area in the distance may have caused the pilot some difficulty. No engine problems were reported in any of these cases.

ANALYSIS

There is no motivation to purposefully fly close to a wire. One explanation for such an accident involves the lack of sufficient power to accomplish the desired trajectory (maybe cross winds were at fault).

The presence of a light as shown in figure 5-7 may have had two effects. A light so located could have made it more difficult to see the wire. In addition, if the lighted area was substantially below the takeoff area, and the remaining area was very dark, the pilot may have been misled as to the horizon reference. Since the takeoff is a heads-out, eyes out event and the pilot would not reference the altitude indicator to select the acceleration altitude, he would then look outside and use the reference found there. If the reference available provided the pilot with a depressed horizon line (below the earth horizon), the pilot may have been induced to over rotate (nose down) during the initial departure acceleration. Having over rotated, there may have been insufficient power to climb out over the wire, and too little room (or time) to flare and stop.

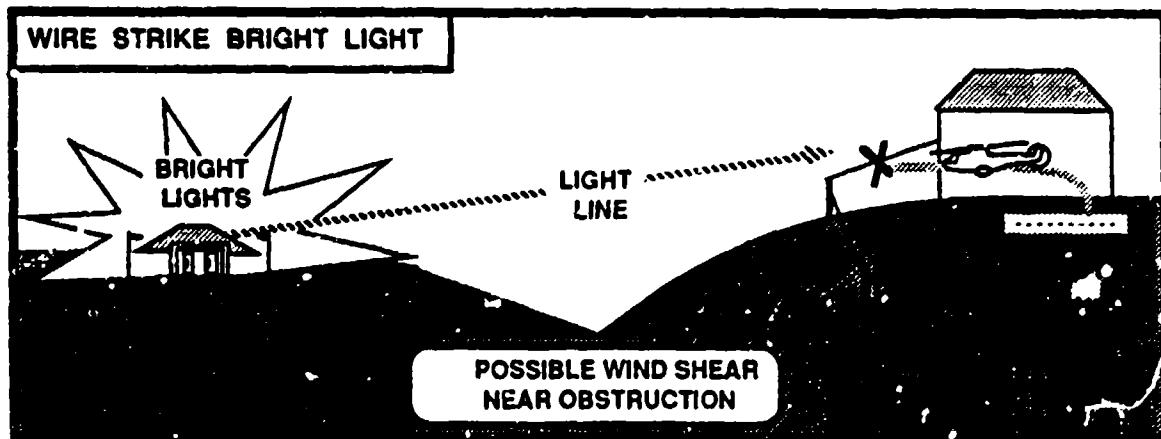


FIGURE 5-7. VERTICAL TAKEOFF INTO WIRE FROM HELIPORT

TAKEOFF FROM HIGHWAY (NIGHT) WIRE STRIKE SCENARIO (5C)

The pilot accomplished a low reconnaissance before turning on final and conducting a safe approach and landing on a highway at night. The pilot observed a power line running parallel to the highway but failed to see a second wire crossing the road which the pilot subsequently used for the takeoff run. After the pickup, the pilot used an ICE takeoff technique to depart along and above the road. The aircraft struck the wire just after the pilot rotated the nose to climb (see figure 5-8). In some cases, bright lights are in the pilot's field-of-view. In other cases, the takeoff is into a very dark area.

ANALYSIS

After completing the pickup, the pilot put the nose down and accelerated forward prior to initiating a climb. During this acceleration, the pilot was concentrating on: (1) altitude (road clearance), (2) power management (achieve and maintain full power) and (3) airspeed. The pilot observed the airspeed indicator begin to operate and then indicate the speed for the best climb angle at which point he rotated the nose up. (Airspeed is also an indicator of improved flying qualities.)

The pilot knows that when the nose comes up and the aircraft climbs away from the ground, the visual cues available for flight path management will suddenly diminish to almost nothing. If the departure is into white (auto) lights, or if a landing light is used for takeoff, a finite period of time is required for the pilot's eyes to adapt to the dark night visual cue system.

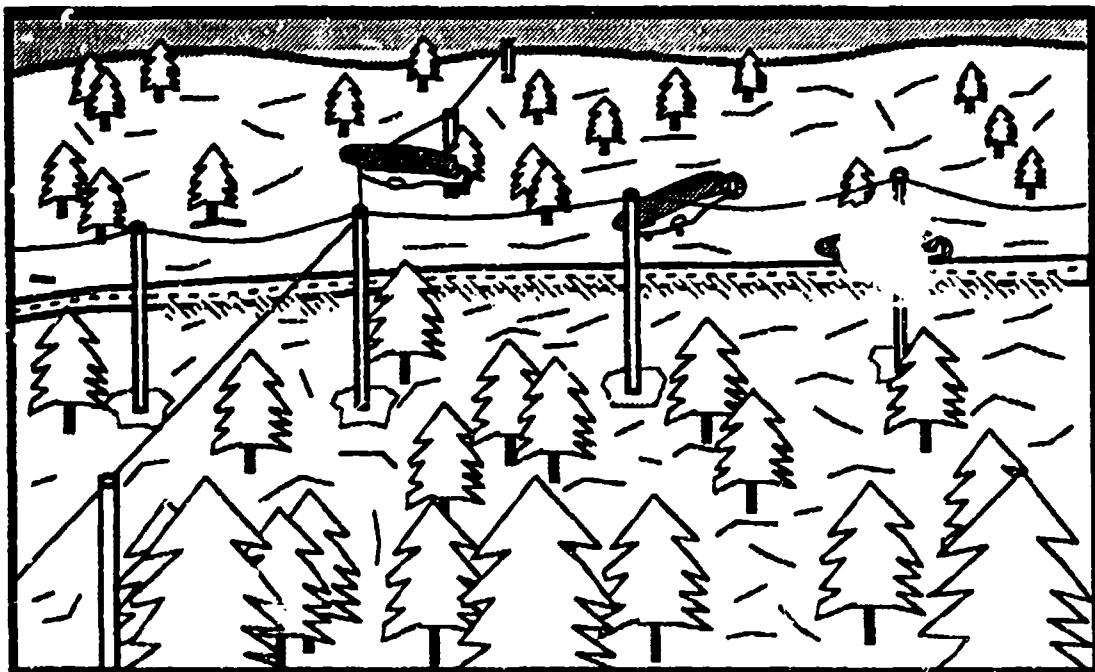
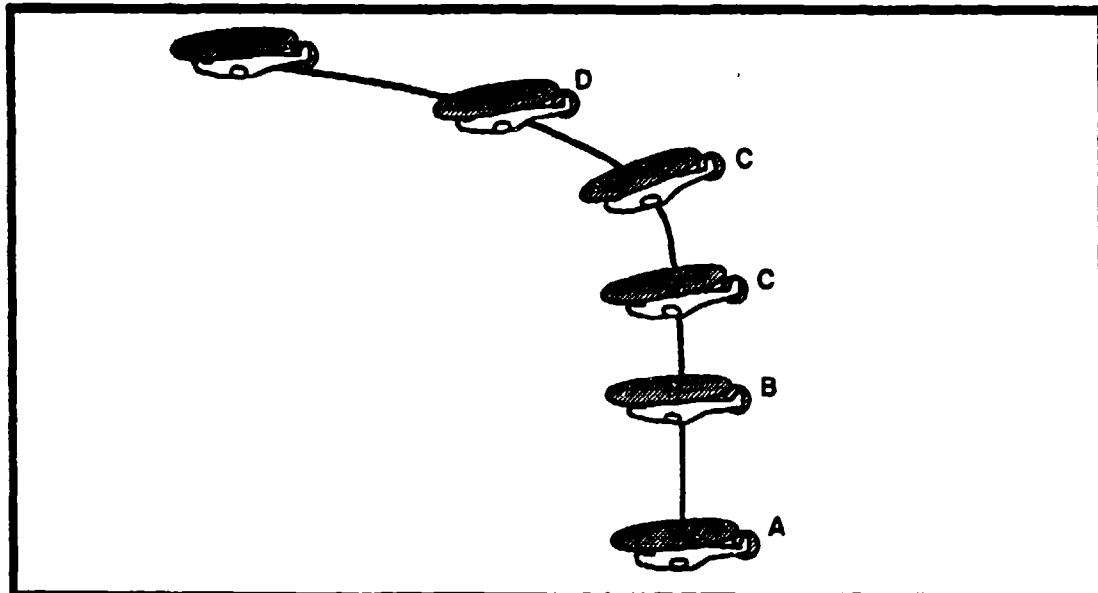


FIGURE 5-8. NIGHT TAKEOFF INTO WIRE

The pilot is experienced and is aware of the dramatic loss of cues during the transition to forward climbing flight. This knowledge causes the pilot to transition to an "eyes in" mode as quickly as possible. This anticipated need to get the eyes and mind back "inside the cockpit" reduces that portion of the pilot's scan which is available to detect and recognize hazards such as wires crossing a departure route (that the pilot has already checked).

In defense of the pilot, many helicopters are not vertically agile. If it had a sufficient margin of power available, (and maybe two engines, considering the nature or shape of the height-velocity (HV) diagram), the pilot could use a different departure technique. The pilot could have departed with a great deal more verticality. A vertical departure produces a flight path which is dramatically less likely to involve an obstruction (see figure 5-9).

With a vertical rate established, the pilot gradually depresses the nose attitude and the aircraft starts to accelerate while climbing. The success of this departure is dependent upon power, good slow speed flying qualities, and good cockpit displays. A radar altimeter would be a great aid during the initial minutes of the departure. When compared to the running takeoff, the vertical departure also provides a more acceptable visual transition.



PROCEDURE:

- A
 - Hover high IGE, check power available.
 - Adjust lights to provide X-Y ground speed cues and reduce backscatter of light into cockpit.
 - Smoothly add power to obtain 300 ft/min to 500 ft/min vertically.
- B
 - Passing 100 feet ACL, start to ease the nose down 3 to 5 degrees.
- C
 - Maintain no less than 500 feet/minute during push-over.
 - Lights-off when no longer effective.
- D
 - When the airspeed indicator starts to operate normally, continue to climb using "best climb" techniques until at least 500 feet above ground .

FIGURE 5-9. VERTICAL TAKEOFF DEPARTURE TO AVOID OBSTRUCTIONS

OBSERVATIONS AND FINDINGS

The majority of the accidents reported in this section could have been avoided if more verticality had been employed in the takeoff trajectory. The increase in vertical displacement from the ground would have taken the aircraft out of the obstruction rich environment which exists below 50 feet. This technique is not a feasible alternative for operators of older aircraft because of power considerations. But the increased verticality is easily accomplished within the constraints of all FAA regulations when modern multi-engine aircraft are employed.

Older single-engine aircraft routinely operate at near maximum gross weights. The pilots of these aircraft are faced with the need to make maximum performance takeoffs over obstructions on a routine basis but are only somewhat aware of the powerful aerodynamic characteristics which are related to relative wind. This is especially true in the case of cross wind during takeoff. These pilots are therefore operating without adequate information.

Some of this wind related performance information is general in nature and can be readily compiled and disseminated. Other factors are aircraft unique and require special data preparation. The eventual availability of this data will improve the basic awareness of helicopter pilots, expand the opportunity for professional behavior and reduce accidents.

An advanced helicopter handbook should be developed to provide more detailed information on helicopter performance and flying qualities along the lines of reference 32, AC 61/13B, "Basic Helicopter Handbook", and reference 33, "Rotary Wing Flight," by Ean Nicholas. This handbook should be written with both single - and dual civil pilot operations in mind.

SECTION 6

CLEAR DAY WIRE STRIKES, EN ROUTE

OVERVIEW

A number of "wire strike" accidents occurred during flights which responded to a customer's desire to fly to some remote location and inspect the terrain or some structure on the terrain. These accidents did not involve an attempt to land or depart from a hover. All involved clear days, although the sun and other factors did add a degree of difficulty to the visual task during some events. The pilots were all legally qualified to conduct the flight. (Note: Certain deliberate low altitude operations such as agricultural spraying were considered to involve special high risk characteristics and were not treated in this study.)

RIDGE LINE SCENARIO (6A)

This flight profile is best characterized as being free-flowing, with numerous turns to follow contours and ridge lines. Pilots reported (in accident summaries) that during such flights, they often made quick descents or turns in response to a customer's need to inspect a surface feature. Sometimes these maneuvers were in response to a passenger's request. Similarly, quick maneuvers were conducted on the pilot's initiative as well.

In the case considered here, the client requested a 90 degree turn to cross a ridge to the left of the course being followed (see figure 6-1). The (single) pilot immediately started a left turn to the new heading. This required a turn into the pilot's blind side. The ridge was somewhat above the starting altitude, requiring the pilot to start an immediate climb while turning. Approaching the ridge, the aircraft was subject to mild downward air mass movement as a head-wind flowed down the back side of the ridge. Crossing the ridge, the aircraft impacted a pair of local power wires and crashed. The pilot saw the wires at the last second, but was unable to execute a vertical maneuver to avoid contact. The wire was too low to fly under and too high to get over. The aircraft was not equipped with wire cutters.

ANALYSIS

The pilot was experienced and knew wires were all through the local terrain. He also knew that trees and bushes often camouflaged, and sometimes totally concealed, poles which supported wires that cross valleys, rivers, and saddleback depressions in ridge lines. As the aircraft approached the ridge, it was evident that the crossing would involve a fairly low crossing clearance, but the pilot rejected the option to conduct a 360 degree climbing turn. This option was discarded because the pilot concluded that there was no obstruction and the turn would waste time. A 360 degree turn might even have transmitted the impression that the pilot was having trouble flying the aircraft and alarm the passenger.

The need to climb motivated the pilot to slow down to the speed for best rate of climb (to improve climb performance). The decelerating flare undoubtedly produced a

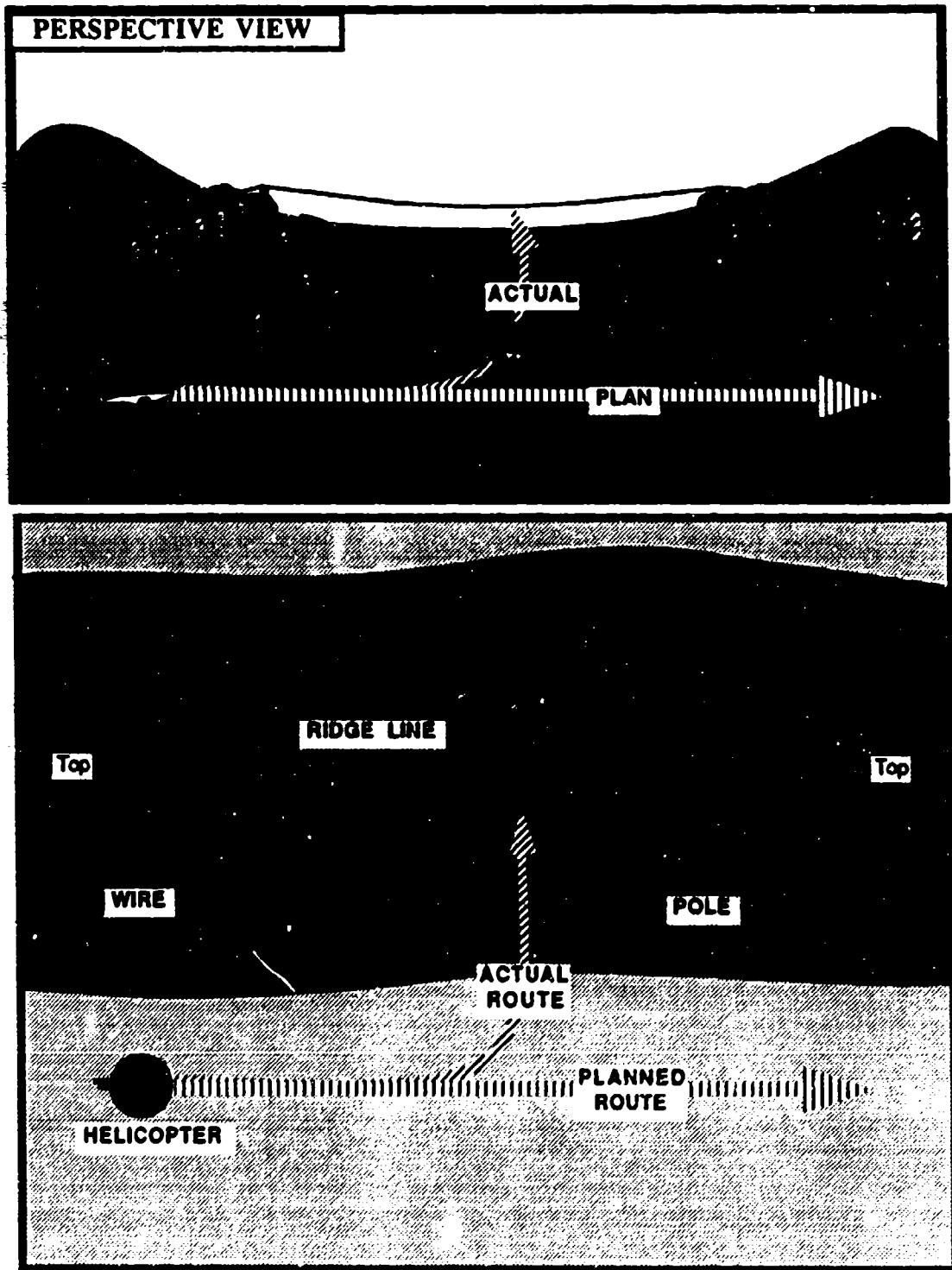


FIGURE 6-1. CLEAR DAY, RIDGE LINE WIRE STRIKE

short term climb and the slower speed gave the pilot more time to scan for obstructions, but it did not represent the best initial choice of a climb speed for this situation. The pilot should have opted for a higher climb speed to retain a margin of energy (increased speed provides increased kinetic energy) for see-and-avoid

maneuvers or to egress from a down draft (common in mountain operations). If the pilot slows too much, the rate of climb may drop dramatically. For example, if the pilot slows below the minimum airspeed for level flight (figure 6-2), the aircraft will descend. Had the pilot maintained a climb speed which was even slightly higher than the speed for best rate of climb, the pilot would have been in position to trade airspeed for a 180 degree turn (to retreat away from the ridge in case of a problem) or to conduct a pull-up maneuver (to clear an obstruction detected at very short range).

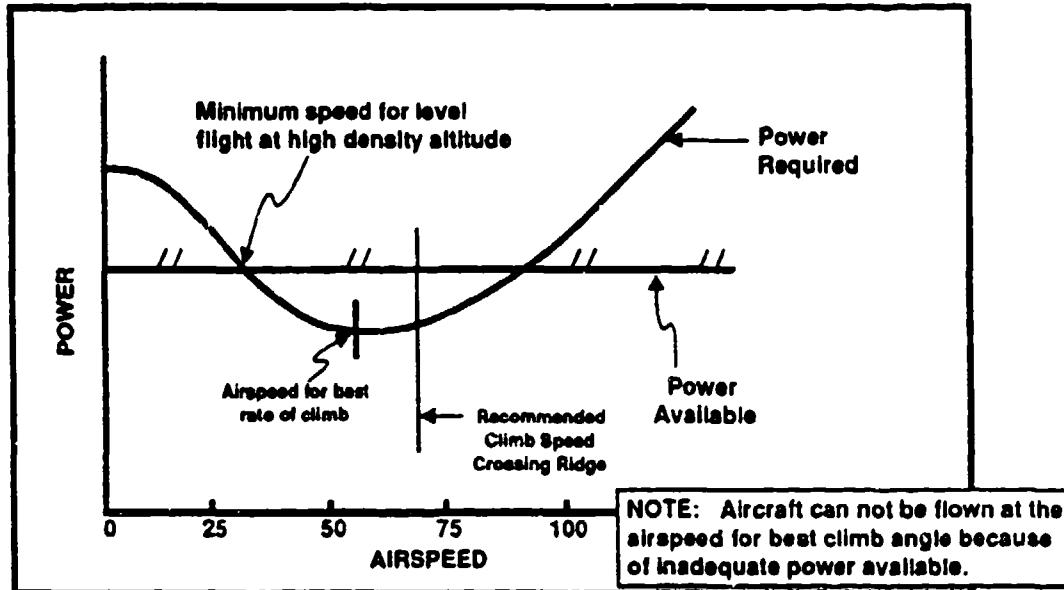


FIGURE 6-2. INSUFFICIENT POWER FOR ROBUST VERTICAL AGILITY

Had the pilot attempted to climb at the higher speed, only to discover that the aircraft would not climb, this would have been a clear warning to abort the attempt and turn away immediately. Figure 6-2 illustrates the performance details of these alternative strategies in terms of power available and power required. The figure shows that if the pilot slows early, say to 45 knots (just as an example in this case), the angle may be improved but there is no margin of airspeed to (1) employ during an up-and-over obstruction avoidance maneuver or (2) turn away from rising terrain. If a speed of 65 knots or greater had been maintained approaching the terrain, the climb angle should still have been good, plus both escape alternatives would have been available.

In this case the pilot soon realized that the flight path would be dangerously close to the crest of the ridge. This realization was followed by a second flare to trade airspeed for altitude. This may have caused the aircraft to slow to the speed for the best climb angle (an inadvertent result), or it may have caused the aircraft to decelerate to a speed which would no longer support level flight because of inadequate power.

If a crossing is attempted with a small margin of speed and/or climb performance, and a wire is discovered at very close range (and it is impossible to fly under), the pilot has three options: (1) pull the nose up at the last minute and flare over the wire, (2) pull up on the collective (and trade rotor speed for short term lift), or (3) both (1) and (2). This ability to "jump" over a barrier obstruction (such as a wire) is characterized as "vertical agility."

Large power margins are required to achieve good slow speed vertical agility (see figure 6-3). Pulling up on the collective commands an instantaneous vertical acceleration and if the power commanded does not exceed the power available, the rotor speed will normally stay in the safe region. Quick pull-ups (flares) from 60 to 30 knots will also provide a very useful (additional) transient climb, further increasing vertical agility. An aircraft with the performance margins depicted in figure 6-3 exhibits robust vertical agility and will climb well even if the aircraft is slowed to 30 knots.

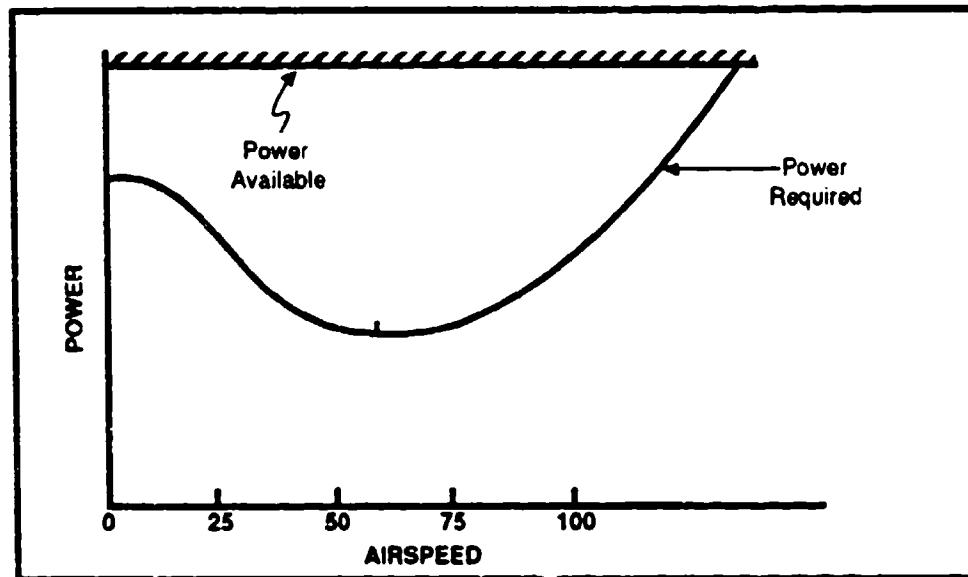


FIGURE 6-3. AMPLE POWER FOR ROBUST VERTICAL AGILITY

In some aircraft, a pilot can lose sight of the obstruction during a pull-up (flare) maneuver. Concern for this possibility sometimes causes pilots to delay the flare portion of an up-and-over avoidance maneuver, first employing "a collective only" technique and only using the flare if it becomes obvious that it is essential to the success of the event (see figure 1 of reference 16). Pilots also know that an abrupt pull-up can induce blade-stall on some aircraft if the aircraft is operating near its ceiling. Thus concern for blade-stall will also cause pilots to use the collective first and a slow flare if time permits.

In summary, helicopters are designed to have a slow speed vertical maneuver capability which facilitates operations in proximity to terrain and obstructions. Yet in practice this capability varies between aircraft, and for a given aircraft vertical agility will vary dramatically as a function of loading and density altitude. This means that pilots operating in mountainous terrain must be very aware of mountain slope wind effects, power required/power available relationships, and the speeds for best climb performance.

FAULTY RECONNAISSANCE, DRY RIVER SCENARIO (6B)

In this composite scenario the pilot desired to descend into a dry river bed to allow a passenger to inspect a pipe line crossing. The pilot flew a reconnaissance over the area and determined that it was clear. Nevertheless, the aircraft struck a wire as it descended below the top elevations of the river bank. The wire was not supported by poles on either end. It came out of the river bank (see figure 6-4).

ANALYSIS

Descents into depressions such as river beds and canyons, must be considered to be high risk operations unless the pilot is intimately familiar with the area. The more remote the area, the lower the probability that small power lines will be present. The more populated, the higher the probability. Regardless, the prudent pilot should never fly into a depression that has not been previously inspected, close-up.

It is possible for skilled pilots to fail to detect a wire during an overhead inspection. In one instance, the wire crossing a depression was connected to tree trunks. In another, the only supporting poles were below the upper edges of the depression.

It would appear that situations like this one make a strong argument for increased verticality during approaches to unfamiliar terrain. Failing this solution, wire cutters should be installed on aircraft required to enter this environment on a regular basis.

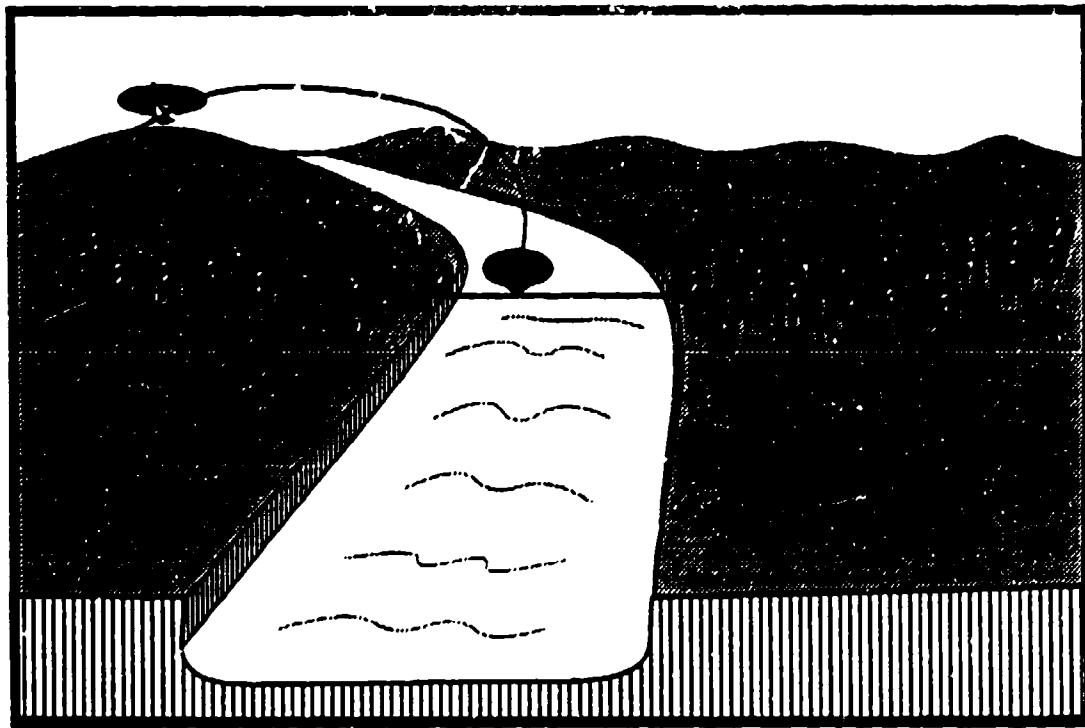


FIGURE 6-4. FAULTY RECONNAISSANCE

RECKLESS TERRAIN - FOLLOWING SCENARIO (6C)

A third composite accident type involves following river beds and roads for fun (see figures 6-5 and 6-6). Most of the accidents which contributed to this composite involved unnecessarily low altitude operations, with a majority of the events involving a turn just prior to wire contact. It also appears that the majority of these accidents involved turning into the blind side. That is, if the pilot is in the right seat, a turn to the left is considered to be into the blind side.

ANALYSIS

Flight which is conducted close to the terrain is hazardous. Flight which is conducted close to the terrain and includes numerous turns to follow a road, river or canyon is extremely hazardous. This is because the geometry of the cockpit obstructs vision during turns and leaves insufficient time to detect wires and avoid them. In addition, if a wire is detected in a turn, the pilot must first roll out of the turn before initiating an evasive up-and-over maneuver. Pilots are often surprised by the poor vertical agility of their helicopter during attempts to avoid wires. This comes from lack of maturity or experience in the aircraft.

The higher the density altitude and the closer to maximum gross weight, the more likely the aircraft will not clear an obstruction. These accidents tend to be more of a problem with "personal" operation as opposed to "business" or "air taxi" operations. The small, low cost helicopter tends to exhibit limited vertical agility (ability to use either excess power or speed to accomplish a rapid increase in altitude).

In summary, there is generally no valid mission oriented reason for very low altitude operations along roads or rivers. Thus, such operations appear to represent reckless disregard for flight safety.

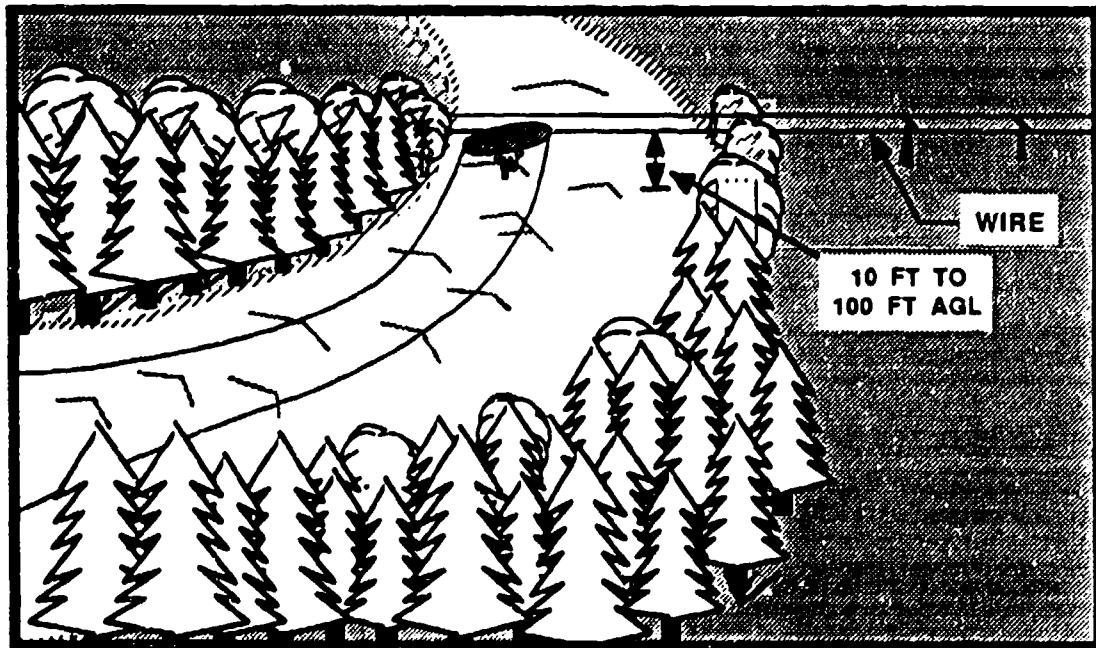


FIGURE 6-5. RECKLESS RIVER FOLLOWING OPERATIONS

OBSERVATIONS AND FINDINGS

Wires are clearly very difficult to detect, even in clear air during daylight operations. Wires on low supports are often very difficult to see but there is no reason to operate a helicopter at such low altitudes. Higher wires are more easily detected but they are more dangerous because of their height. These higher wires typically involve large supports and often have cleared right-of-ways below. This right-of-way can become the important signature or tell-tail for pilots to search for during reconnaissance.

A review of the related accidents suggest that all of these accidents could have been avoided by flying no lower than 200 feet (AGL on radar altimeter). All wire strikes were at or below 100 feet AGL.

Judgment training is required which emphasizes the following points:

- 1) Never fly below 200 feet AGL while following a road or river bank, even if the area is well known.
- 2) If it is essential to enter a depression which may involve wires that are difficult to detect, approach the area from several directions to take advantage of lighting and terrain background which may aid wire (or wire support) detection. When possible use verticality in the approach.
- 3) Pilots should develop a thorough understanding of the power required curve and learn to avoid flying into situations which may induce them to flare and decelerate to the backside of the power required curve while in proximity to terrain which may require robust vertical agility.
- 4) Pilots should never approach a ridge line without sufficient speed and altitude to clear the ridge by hundreds of feet.

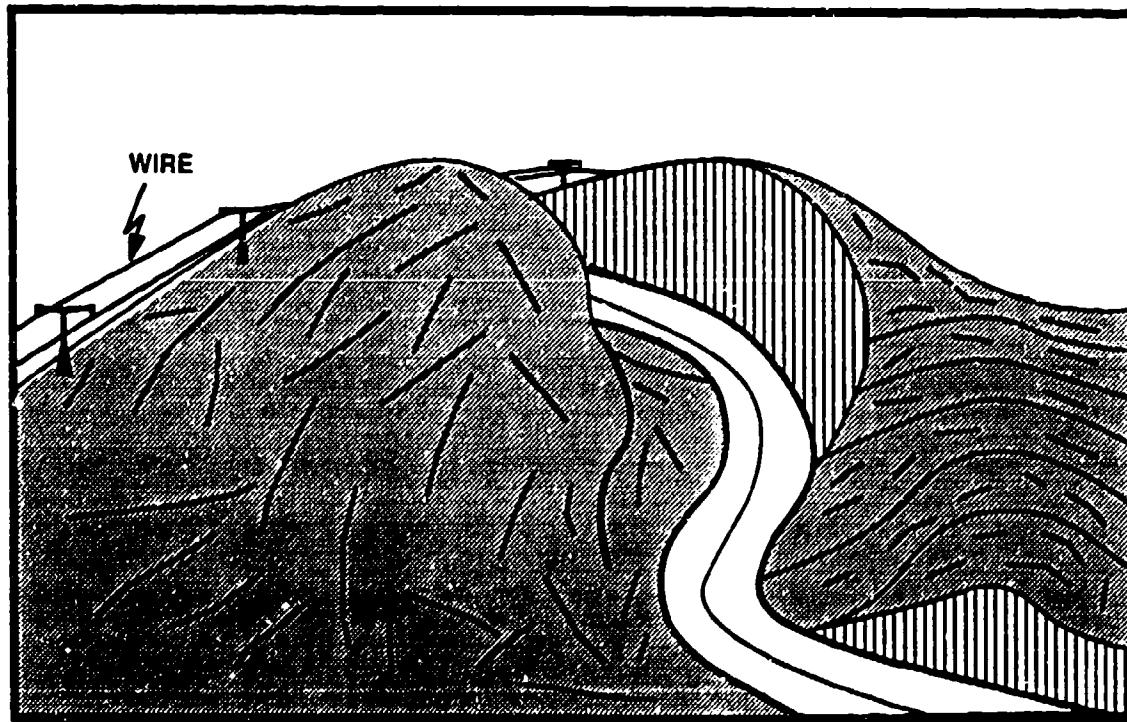


FIGURE 6-6. RECKLESS ROAD FOLLOWING OPERATIONS

SECTION 7

DAY VISUAL EN ROUTE OPERATIONS

OVERVIEW

En route accidents have some common characteristics. Typically, the crew starts out to fly from one point to another. There may be several waypoints en route, but not many.

At some point during the flight, the crew concludes that the weather has deteriorated and a course change is required to circumnavigate the weather. This new strategy also includes numerous decreases in altitude and at some point, when forward visibility becomes very poor, the pilot will attempt to decrease airspeed. The flight then terminates in one of the following ways:

Descending, Decelerating Flight Straight Ahead

- wire strike
- tree strike
- terrain (surface) strike

Turn to Retrace, Descent into Surface

ROAD FOLLOWING WIRE STRIKE (DAY) SCENARIO (7A)

The pilot departed one hospital for another under apparently satisfactory weather conditions and intended to go direct using electronic navigation means. Shortly after the flight commenced, the pilot determined he was not going to be able to fly direct as originally planned (figure 7-1). Instead he elected to follow a highway. Subsequently, the visibility along the newly selected route became less and less acceptable. Eventually the pilot determined that the weather situation was not going support continued flight along the highway, and the pilot decided to turn around and return to the point of departure. At this point, the aircraft was flying no faster than 90 knots.

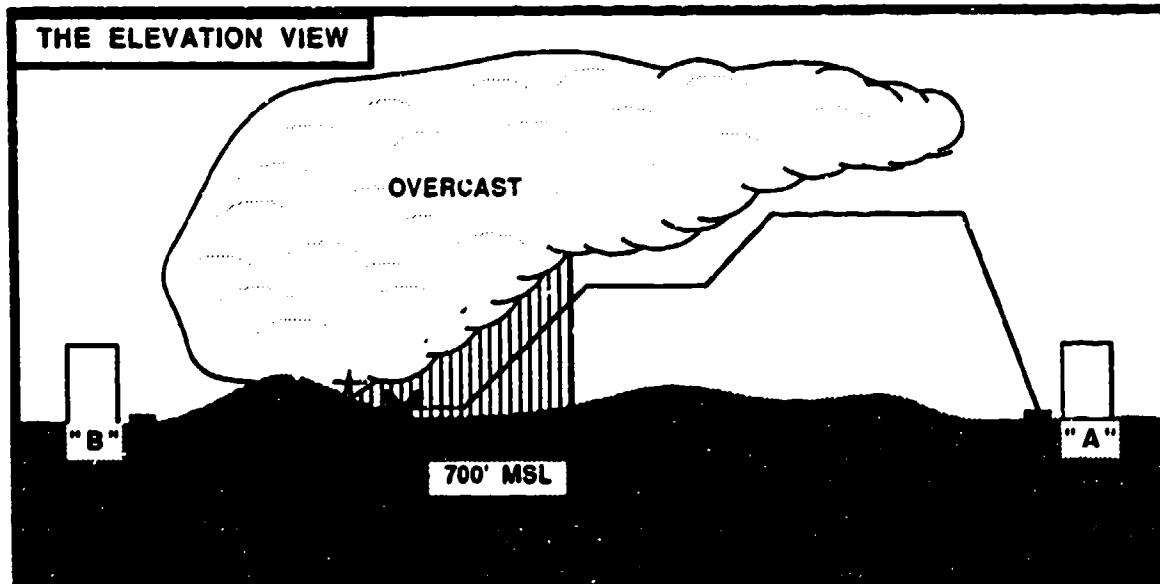


FIGURE 7-1. TYPICAL EN ROUTE FLIGHT PROFILE

The crew observed the pilot lower the collective and understood that he was attempting to decelerate to 60 knots. The pilot wanted to first slow down and then conduct a 180 degree turn so that he could retrace his route back to the point of departure. Before the aircraft could be turned, it struck wires crossing the highway at about 70 feet AGL (figure 7-2A).

ANALYSIS

This aircraft was flying too low to start with and probably lost altitude during the deceleration (figure 7-2B). The pilot was probably attempting to retain a forward visual scan to look for obstructions. The pilot may have lowered the collective too much during the flared deceleration and inadvertently descended.

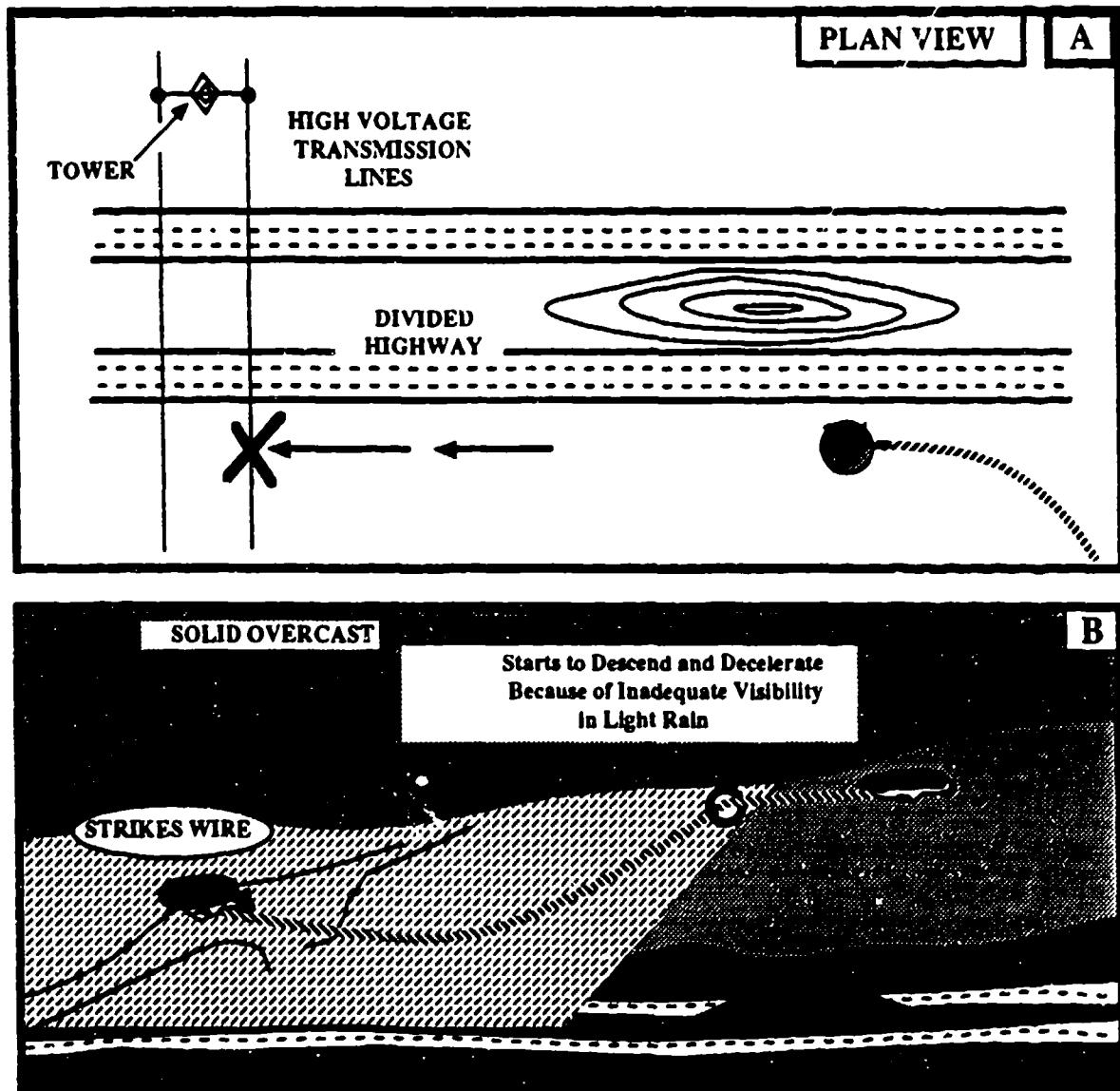


FIGURE 7-2. HIGHWAY FOLLOWING WIRE STRIKE

The pilot was reported to have descended numerous times along the route (at constant airspeed) before the accident. The initial flight altitude was about 1,000 feet AGL. This altitude suggests that the visibility was probably at least 3,000 feet. The 3,000 feet visibility assumption is based upon the pilot's desire to see the terrain ahead. This surmises that the pilot has a look down capability of 15 to 20 degrees while operating at cruise airspeeds. A look down angle of this magnitude equates into a visual range which is about three times the height of the pilot's eye.

When a pilot encounters decreasing ceilings or decreasing visibility, the natural reaction is to descend. Figure 7-3 illustrates the effect of decreasing visibility; this is the factor which is underappreciated. If the visual range decreases to roughly 1,000 feet, the pilot of most helicopters will probably have descended to about 300 feet AGL, maybe lower. Concern for wires crossing a road will typically cause a prudent pilot to stay above 200 feet AGL as long as possible.

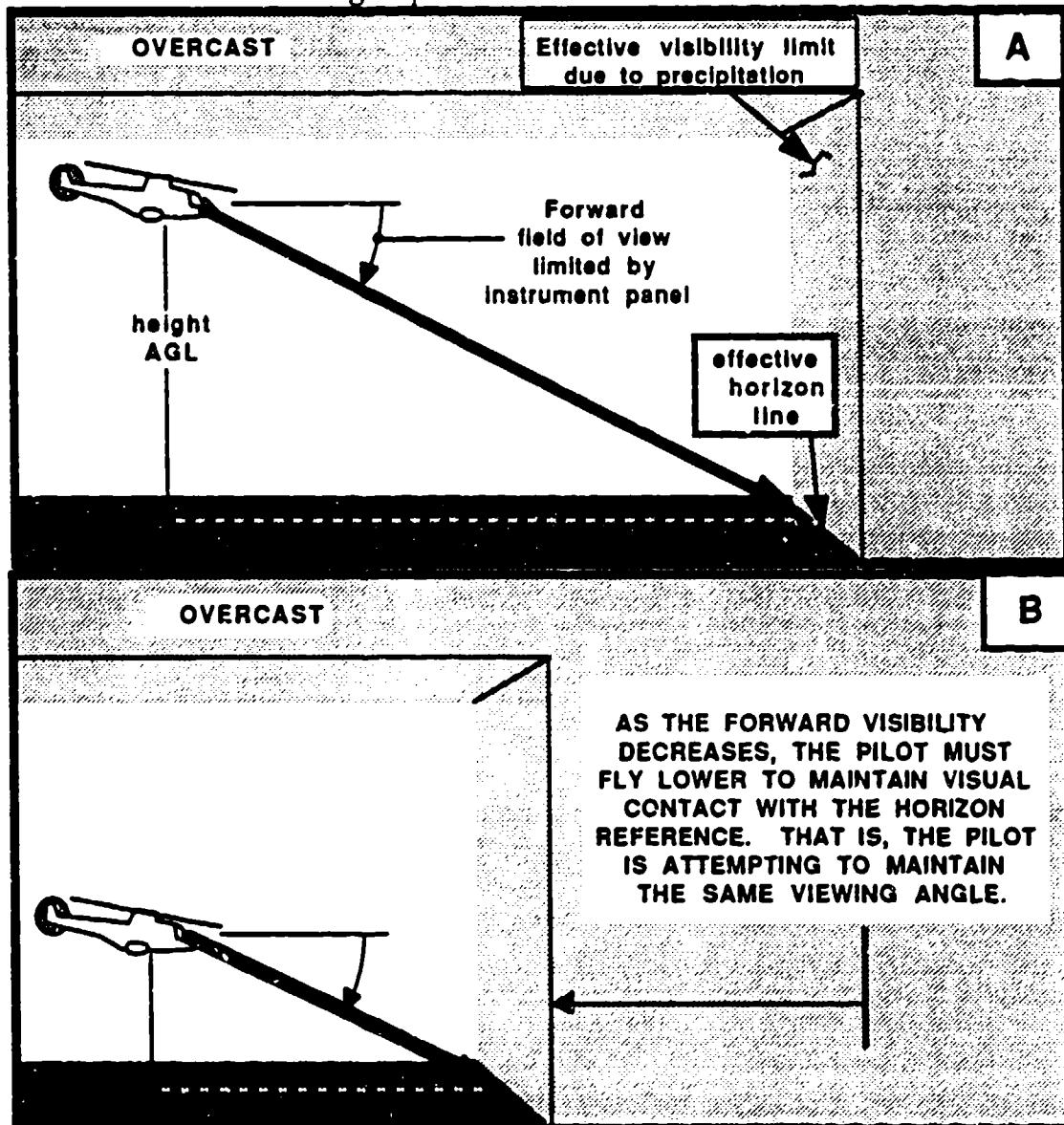


FIGURE 7-3. SHORTENED VISIBILITY DICTATES LOWER OPERATING ALTITUDES

Having descended to some minimum safe altitude, the pilot may continue to fly faster than he should to help maintain a nose down attitude, thereby improving his ability to see out. The nose attitude of most helicopters is increasingly nose down as the aircraft flies faster and faster; and the more nose down an aircraft flies, the better a pilot can see out. Thus there is a natural, often unintentional, tendency to fly fast to facilitate the retention of the view over the nose. The pilot will typically settle on a comfortable speed, often coinciding with cruise conditions.

The above explains the natural tendency of pilots to descend and fly fast in a difficult visual environment. These natural responses often cause pilots to fly into a "low and fast" box they can not safely get out of. In effect, they have flown into a box canyon.

In scenario 7-1, the pilot discovered he had flown into a box canyon when he realized (1) he must descend into the wire environment of the road, (2) he was flying too fast to stop to avoid a wire, (3) a turn away from the road (to turn around at high speed) may result in an inability to find the road again, and (4) when the aircraft departs the road, even taller obstructions must be detected and avoided.

The pilot had an immediate need to slow down. This means the nose must come up in a decelerating flare. Bringing the nose up exacerbates the forward visibility problem (figure 7-4A). To avoid losing forward visibility, the pilot will typically ease the nose up 5 or 10 degrees and then lower the collective. The collective is lowered to decelerate but it is also lowered to fly lower. The pilot must fly lower to retain contact over the nose (figure 7-4B). He may be looking for the towers which support power lines or he may be just trying to keep contact with the ground to meet his cue needs to fly the aircraft.

A large flare attitude change (nose up) in the order of 15 degrees will produce a deceleration of roughly 8 feet/second squared or 5 knots a second. A typical flare (under difficult visual conditions) will result in a deceleration of about one third or one half of this number.

Failure to slow down puts the aircraft in serious jeopardy. For example, if the pilot can see 1,000 feet, the aircraft will cover this distance in 10 seconds at 60 knots. If a pilot was flying at 60 knots and saw an obstruction 1,000 feet ahead, he could probably stop just in front of the obstruction. If the speed was 90 knots, there would be a collision. If the visibility was 600 feet and the speed was 60 knots, there would be a collision.

In the case discussed here, the visibility is assumed to have dropped to 500 or 600 feet. This visual range is probably sufficient to support a gradual deceleration to a hover (20 to 30 seconds). Alternately, it would probably support a 30 knot air taxi at low altitude, to find a safe landing area.

In this case, the pilot attempted to decelerate for the purpose of conducting a minimum radius, 180 degrees turn to improve his forward visibility. Deceleration caused the aircraft to descend into a wire straight ahead. This is consistent with the expectations developed by the above analysis.

The preceding produce two rules-of-thumb.

- (1) When a pilot is just able to see the terrain over the nose (as shown in figure 7-3A), the visual range is roughly three times the pilot's altitude above the surface.
- (2) A typical helicopter requires a distance to stop (in feet) which is equal to twenty times its speed (in knots). That is a 60 knot aircraft requires 1200 feet to stop.

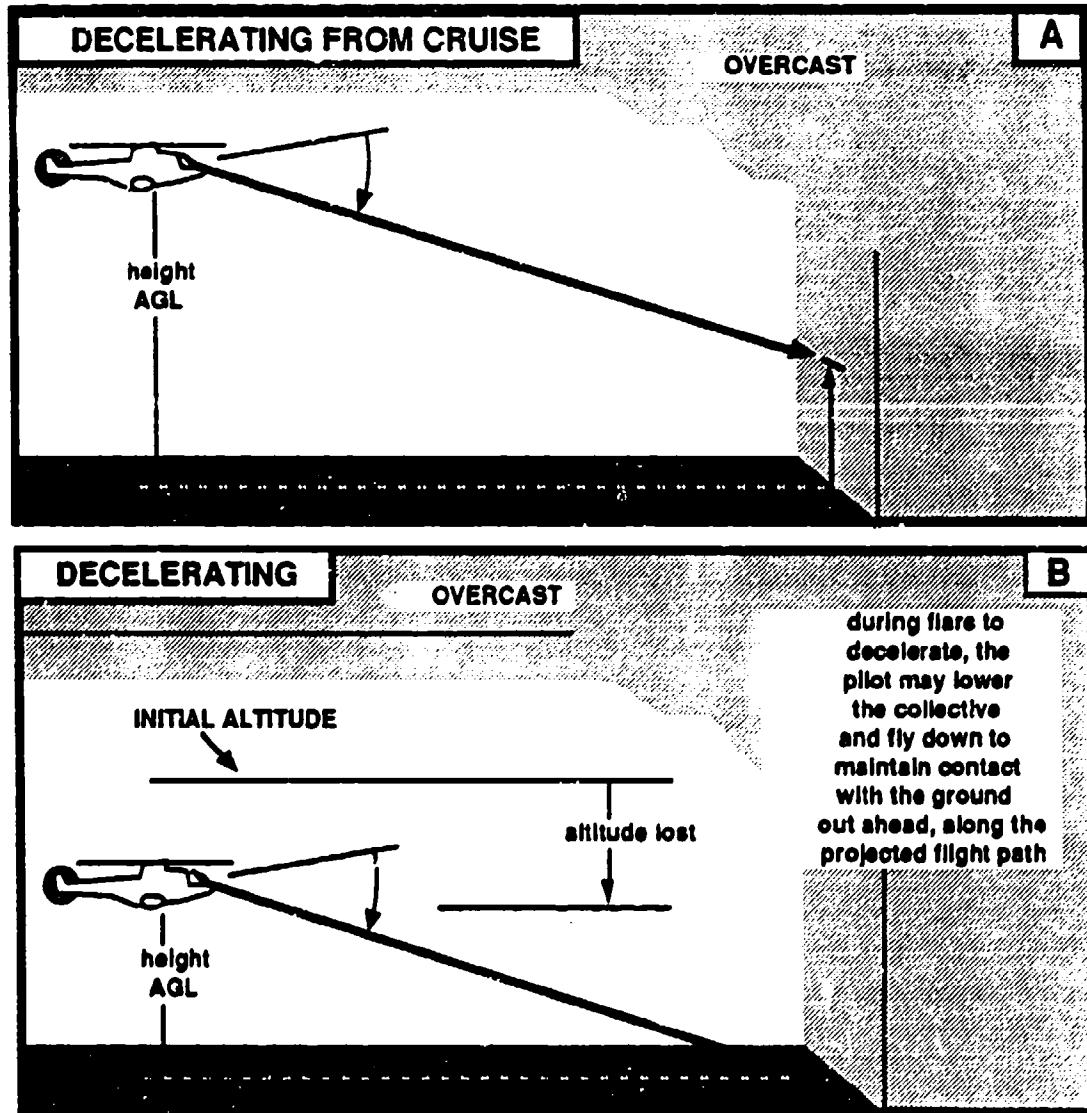


FIGURE 7-4. PILOTS WILL FLY LOWER TO RE-ESTABLISH CONTACT WITH THE TERRAIN AHEAD

REVERSE HEADING - DESCENT SCENARIO (7-B)

The pilot had departed the planned route. The pilot was maintaining a constant altitude of 200 feet AGL while slowing down because of decreased visibility. There was a sudden degradation in forward visibility. The pilot decreased power to descend and stay visual. The pilot rolled to the left to reverse heading and retrace the inbound track. While in the turn, the aircraft continued to decelerate and descend below the original altitude. As the pilot attempted to roll wings level and steady on the outbound heading, the pilot observed a very low airspeed but was unable to stabilize the airspeed or accelerate or climb.

The aircraft struck a tree after completing a 180 degree turn. The surface was gently rolling. The pilot noted that the airspeed indicator had become unreliable just prior to surface impact (see figure 7-5).

ANALYSIS

As noted earlier, a sudden reduction in visibility will often cause pilots to slow down, descend, and turn to egress. In this case, the aircraft was slowed to the point of operating on the back side of the power required curve. This meant that the power setting selected by the pilot for level flight was probably insufficient (see scenario 7-C).

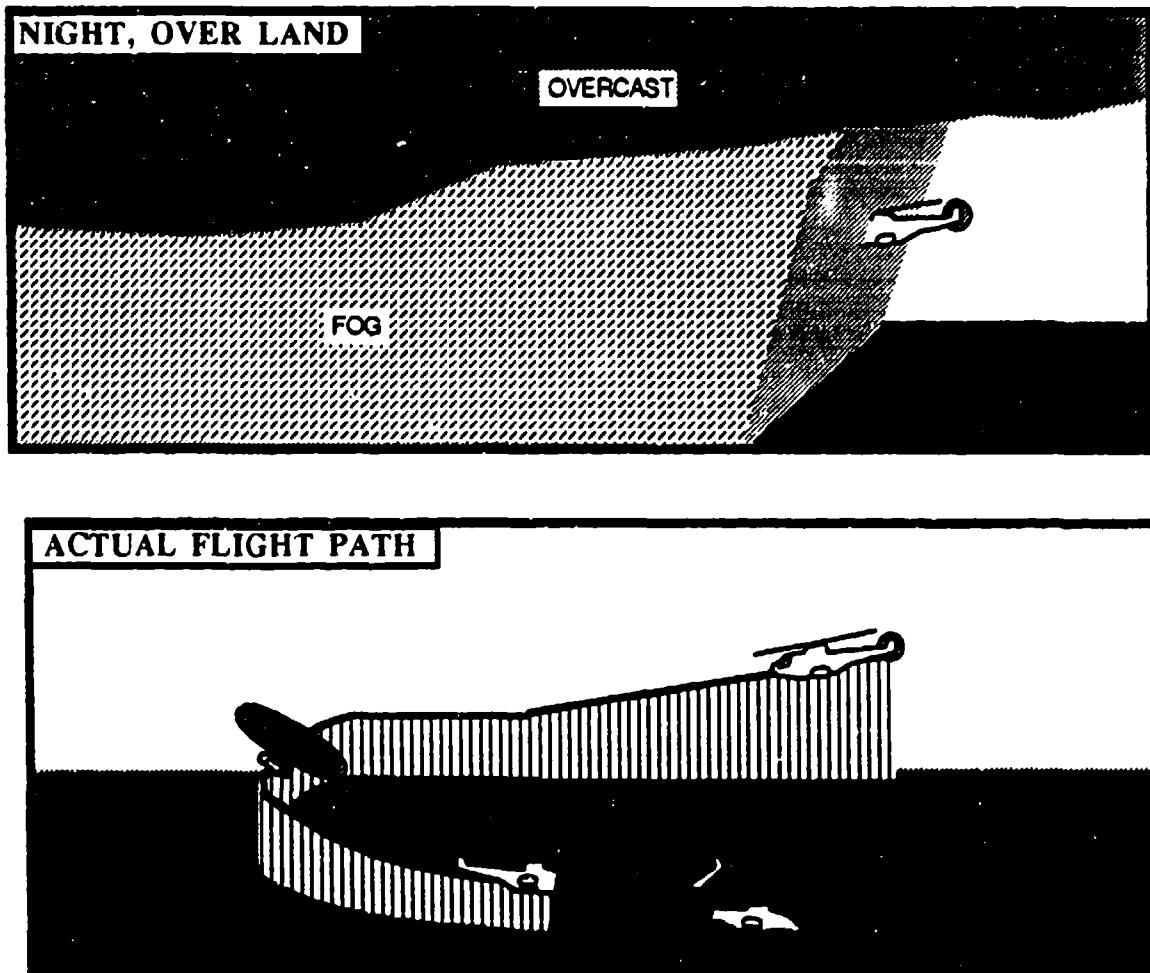


FIGURE 7-5. ATTEMPT TO EGRESS FROM A SUDDEN DECREASE IN FORWARD VISIBILITY

The turn was to the blind side. The pilot was in the right seat. The pilot was not attempting to fly eyes-in and eyes-out during the turn. Although there is a common tendency to turn into the blind side, there is no ready explanation for this preference other than a pilot can keep the instrument panel in his field-of-view while alternately scanning over the panel and out the left door window for spacial references and obstructions. There is a possibility that, failing to see cues over the nose, the cues out the right window were the only ones available. When the pilot rolled into a left bank (in this case), the horizon cues out the left window may have been blocked by the upper door frame and cabin roof. The cues out the right window may have disappeared below the right side window frame. This total loss of peripheral depth cues could explain the pilot's failure to recognize the descent during the turn. This loss of cues might even induce a pilot to fly lower in an attempt to regain the cue line on the right side (see figure 7-6).

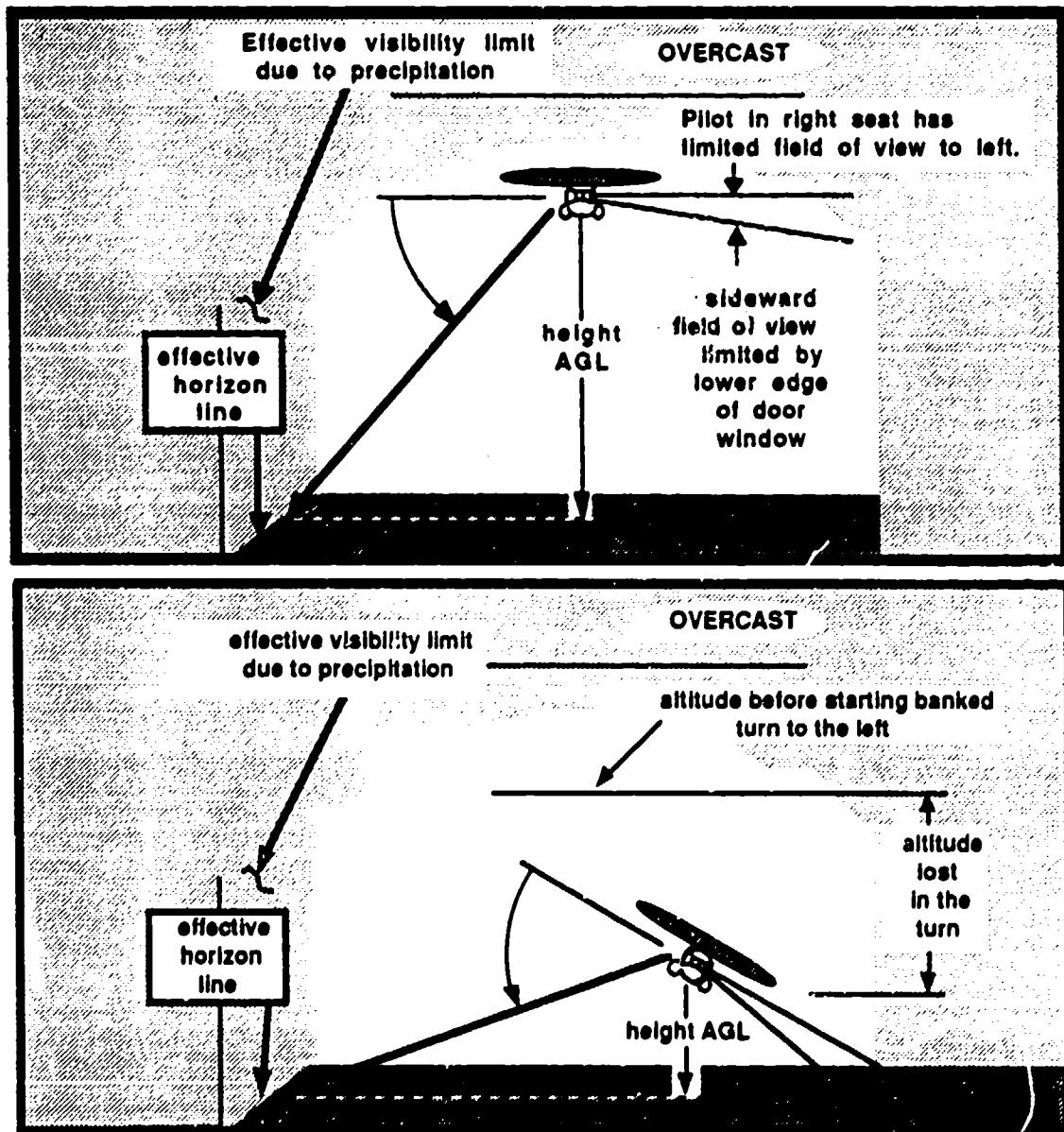


FIGURE 7-6. HORIZON CUES ARE ALSO AVAILABLE OUT THE SIDE WINDOW

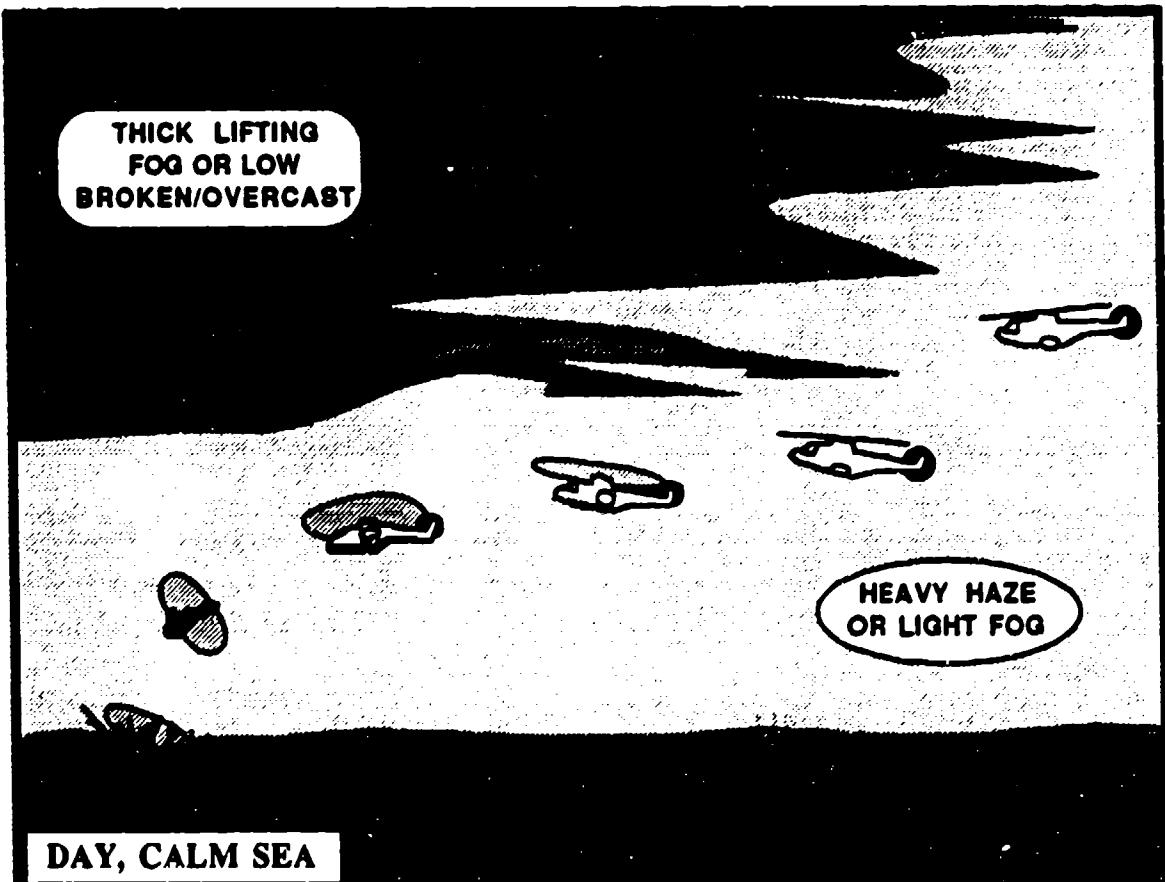
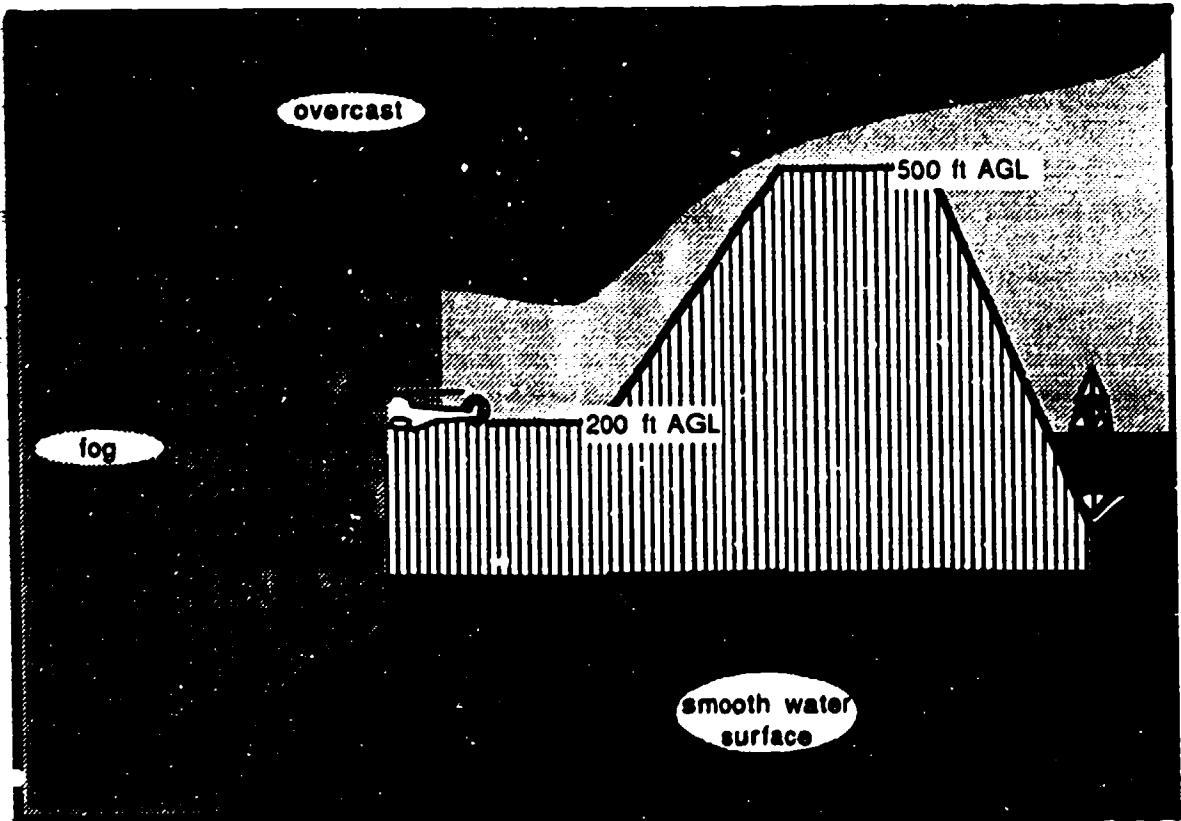


FIGURE 7-7. DESCENDING, DECELERATING TURN IN FOG
OVERWATER, TURNING, INADVERTENT DESCENT SCENARIO (7C)

The pilot was cautiously returning to the mainland from an oil rig. The visibility decreased and the pilot slowed but maintained altitude. Then the visibility decreased precipitously. The pilot attempted to slow again and reverse course to the right. The aircraft slowed, the airspeed became unreliable, control became difficult, there was an uncommanded high rate of descent, and the aircraft struck the water at a very low forward speed (see figure 7-7).

ANALYSIS

In this case, the pilot was turning to the right. This means the pilot was probably attempting to fly using the visual cues available out the right door or window.

The first question involves the descent. If the pilot had set the power for minimum speed and continued to decelerate, the aircraft would descend because the power would be inadequate for constant altitude flight (figure 7-8). The fact that the aircraft was in a banked turn would tend to increase this descent. The pilot was splitting his attention between looking out into the turn, and looking in, to check the operation of the aircraft. At some point, the pilot observed a high rate of descent and reported some difficulty in the control task. The airspeed was now observed to have become unreliable. This is interpreted as meaning that the airspeed pointer was flopping around. This airspeed indication suggests that the aircraft had slowed to some speed below 25 to 30 knots, maybe even to zero. As figure 7-8 would suggest, a rapid sink rate could easily develop as a result of inattention to power during the deceleration. The reported control difficulty is symptomatic of slow speed control coupling and the loss of static directional stability which typically occurs below 30 knots. The control difficulty would normally cause the pilot to re-direct his attention back into the cockpit. The pilot was probably looking in the cockpit, attempting to increase power and arrest the descent, when the aircraft struck the water at a slow forward speed.

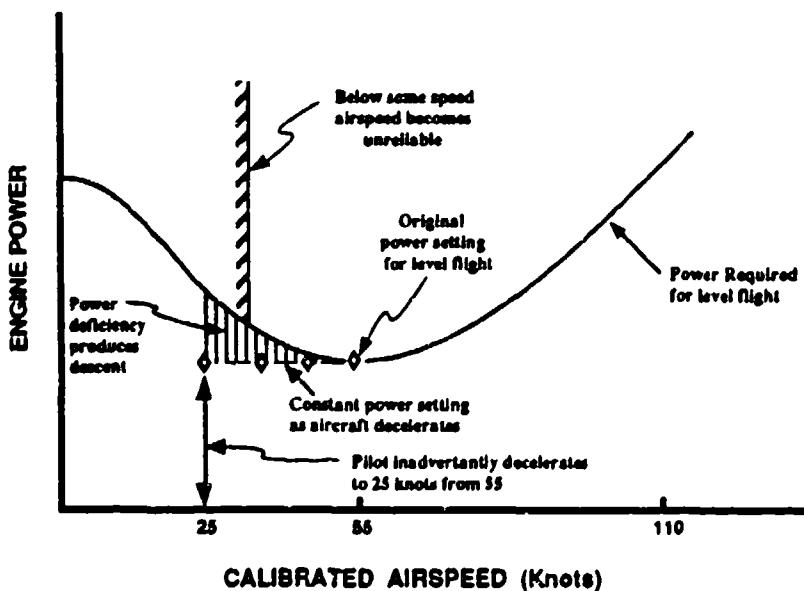


FIGURE 7-8. DESCENT AS THE RESULT OF A CONSTANT POWER DECELERATION
Some airplanes have adequate natural stall warning; others are equipped with stall warning systems which alert the pilot that the aircraft is decelerating to a dangerously

slow speed. The airspeed indicators in airplanes must continue to operate during flight. They typically become unreliable at a speed far below stall speed. The helicopter never stalls, but at least some helicopters do have an equivalent unusable forward flight envelope. That is, at least some helicopters need to be flown at or above some speed, which is above a certain minimum speed, to insure that inadvertent sink-rates, and control coupling problems do not develop during short periods of inattention under difficult visual conditions. The FAA requires all IFR helicopters to be flown above some minimum airspeed during instrument flight. If this speed is observed, none of the above control problems are encountered. On the other hand, there may be some merit in the idea of adding a slow speed warning to provide an alert to a pilot that the slow speed limit is being violated. This improvement could be applied to aircraft approved for operations under difficult visual conditions and instrument flight.

The surface of the water was calm and provided no usable depth cues. Knowing this, the aircraft should have been equipped with a radar altimeter. If it was installed, the pilot was not aware of its indication or the trend in the indicator. Failure to observe the indicator warning might be partially explained by a failure to set the warning altitude high enough to insure satisfactory warning time. Or maybe the only warning was a red light (no horn) and the pilot never saw it.

The failure to see a warning which was available in the cockpit may be explained by examining the direction of turn. When a pilot sits in the right seat and turns right, he must look away from the instrument panel. A pilot in a right seat, must turn left and look left to see the instrument panel and outside view at the same time. Looking left the pilot can fly instruments and glance out. Looking and turning right the pilot must turn his head back and forth. In visual flight, it is reasonable to think pilots will place a priority on looking out, not in. It is also reasonable to conclude that this eyes-out scan technique will cause many pilots to under utilize the cockpit instruments. Cockpit performance instruments are always important to safe visual operations, even on clear days. On a difficult visual day, the use of performance instruments is even more important.

Summary observations: (1) Pilots who rely on instruments probably tend to turn left during efforts to recover from rapidly deteriorating weather. Conversely, pilots who rely on visual reference, turn right. (2) Airspeed indicators can become unreliable during slow speed flight and the condition can go undetected during visual maneuvers in DVC. (3) Warning of impending airspeed indicator failure may be a desirable aircraft system characteristic for operations in DVC. (4) Aural warning of low airspeed or low altitude is most appropriate during eyes-out operations in DVC.

FAILED ROUTE-WEATHER RECONNAISSANCE SCENARIO (7D)

The pilot departed from original flight plan and proceeded direct. He came to a familiar ridge and intended to cross and continue to the destination over a known route (figure 7-9). But before crossing, the pilot attempted to look over a ridge to see if the weather was satisfactory on the far side (see figure 7-10). The pilot was flying in the right seat. He conducted a curved approach, tangent to the ridge line. At that

point the pilot looked across the cockpit to see over the ridge. The aircraft struck an obstruction in a right bank at a moderate speed (figure 7-11). The rock outcropping may have been camouflaged by visible moisture. [Several accidents involved slow flight near the crest of a ridge, to check for weather on the far side. Some involved considerable forward flight speed, while others involved a hovering inspection with inadequate power (see figure 6-2)].

ANALYSIS

It would appear that the flight was conducted much too close to terrain with insufficient altitude AGL to allow for flight path deviation due to pilot inattention, or sudden down drafts, or inadequate hover power for the high altitude condition. The down slope to the right eliminated the possibility of visual cues to judge the height above the near terrain. The pilot may have descended to see over the crest of the ridge but it is more probable that he had no useful altitude cues in the few seconds that preceded the collision. The approach to the point of impact could have involved a gradual deceleration (flare) to airspeeds defining the back side of the power required curve. This could have resulted in a few seconds of undetected descent.

A radar altimeter (if installed) could have provided a useful cue of minimum altitude, but it would not have detected the outcropping ahead. Again, the pilot was flying eyes-out and an aural warning would have been required to alert the pilot of his unacceptably low altitude. There are no useful data on such terrain features, but it appears reasonable to expect that most tall trees, rocks, and pinnacles will be less than 100 feet in height. A minimum altitude of 200 feet AGL would have probably provided safe separation for this event as well as other similar events reviewed but not reported here in detail. This observation appears to be consistent with the obstructions utilized in reference 34.

It is interesting to note that the weather was bad on the far side of the ridge in every event analyzed. This suggests that a low pass near the crest of a ridge line to check the weather is simply a bad idea and should be avoided.



FIGURE 7-9. PLANNED ROUTE OVER RIDGE

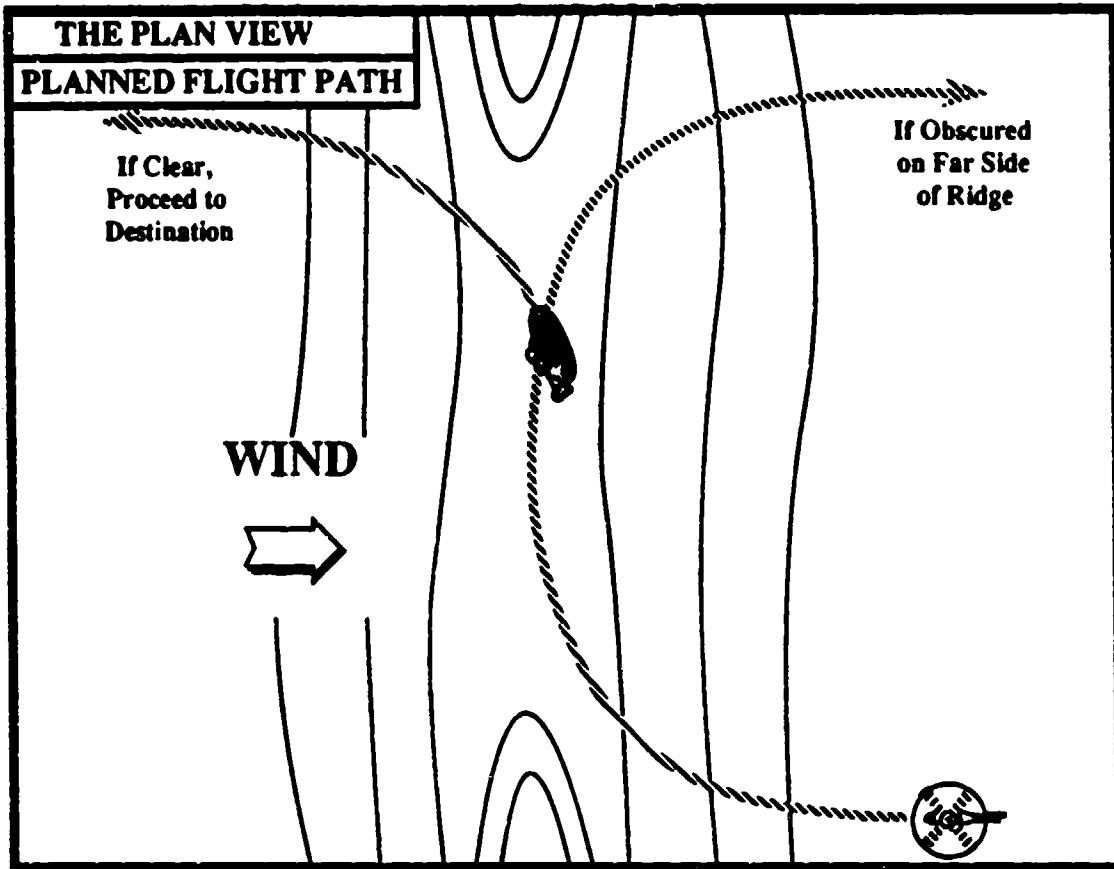


FIGURE 7-10. PLAN TO CONDUCT ROUTE-WEATHER RECONNAISSANCE

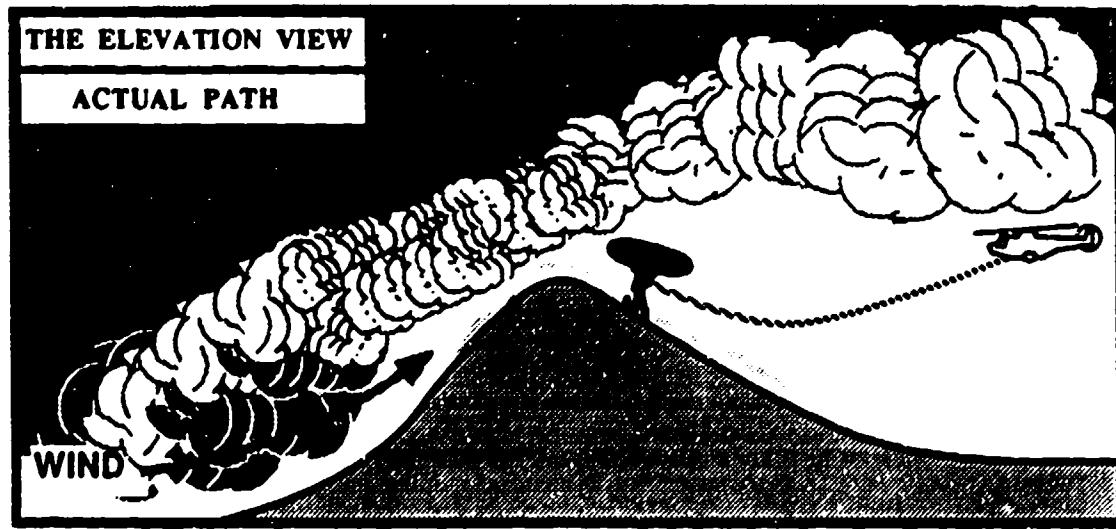


FIGURE 7-11. ROUTE-WEATHER RECONNAISSANCE ENDS IN TERRAIN STRIKE

WEATHER BOX CANYON SCENARIO (7E)

After diverting from the planned route, the pilot elected to follow familiar terrain at a very low altitude. Encountering an up-slope which threatened to force the aircraft into the overcast, the pilot reversed to the left, away from the terrain gradient (figure 7-12). The aircraft slowed in the turn. Completing the turn, the pilot found himself once again in an up-slope condition with no way out. The rotor struck trees as the aircraft completed the 180 degree turn (figure 7-13).

ANALYSIS

The pilot clearly used poor judgment to continue. He had chosen to fly too fast at a very low altitude.

In an earlier analysis, the problem of seeing out ahead at low altitude was examined in detail. To review, it is sometimes difficult to see flight references and obstructions over the instrument panel of some aircraft, especially when they are flown at slow forward speeds, under low overcasts, in heavy haze or fog. Any effort to slow down brings the nose attitude up and makes forward viewing even more difficult.

There may be another problem or two as well. The pilot may fear an inadvertent flare into the overcast. Once the aircraft enters the overcast, the pilot is in a desperate situation. He can not come to a hover and descend slowly to regain visual contact because the aircraft can not be hovered under instrument conditions. The aircraft lacks the stability and control qualities (autopilot functions) and the display characteristics required to accomplish an instrument hover. In fact, most of the helicopters flown into situations such as the one described above are not even suitable for single pilot instrument operations in forward flight.

These aircraft have many flying qualities problems such as the collective to yaw control coupling found in all single rotor helicopters. In forward flight, directional stability of the aircraft suppresses the unwanted heading deviations produced as the result of the collective adjustments, but the situation in a hover and the slow speeds approaching a hover are much different. For example, if the pilot increases the collective to full power from a stabilized hover, and does not adjust the pedal position, most helicopters will rotate about their "Z" axis as they climb vertically. The rate of turn may easily exceed 30 degrees a second, and when they occur in an overcast, such turns will often go completely undetected. The pilot must look at and interpret a spinning heading indicator to detect the turn rate, and this is not a strong piloting display. The heading indicator does not provide the analog cue necessary for quick recognition and response that is found in CRT displays with heading tapes moving left to right, the same way the terrain would be moving if only the pilot could see it.

At slow speeds, an uncompensated collective input causes the aircraft to yaw into a side-slip condition. The aircraft will tend to roll and pitch as the side-slip builds. The pilot must now compensate with longitudinal and lateral control displacements to keep the aircraft level.

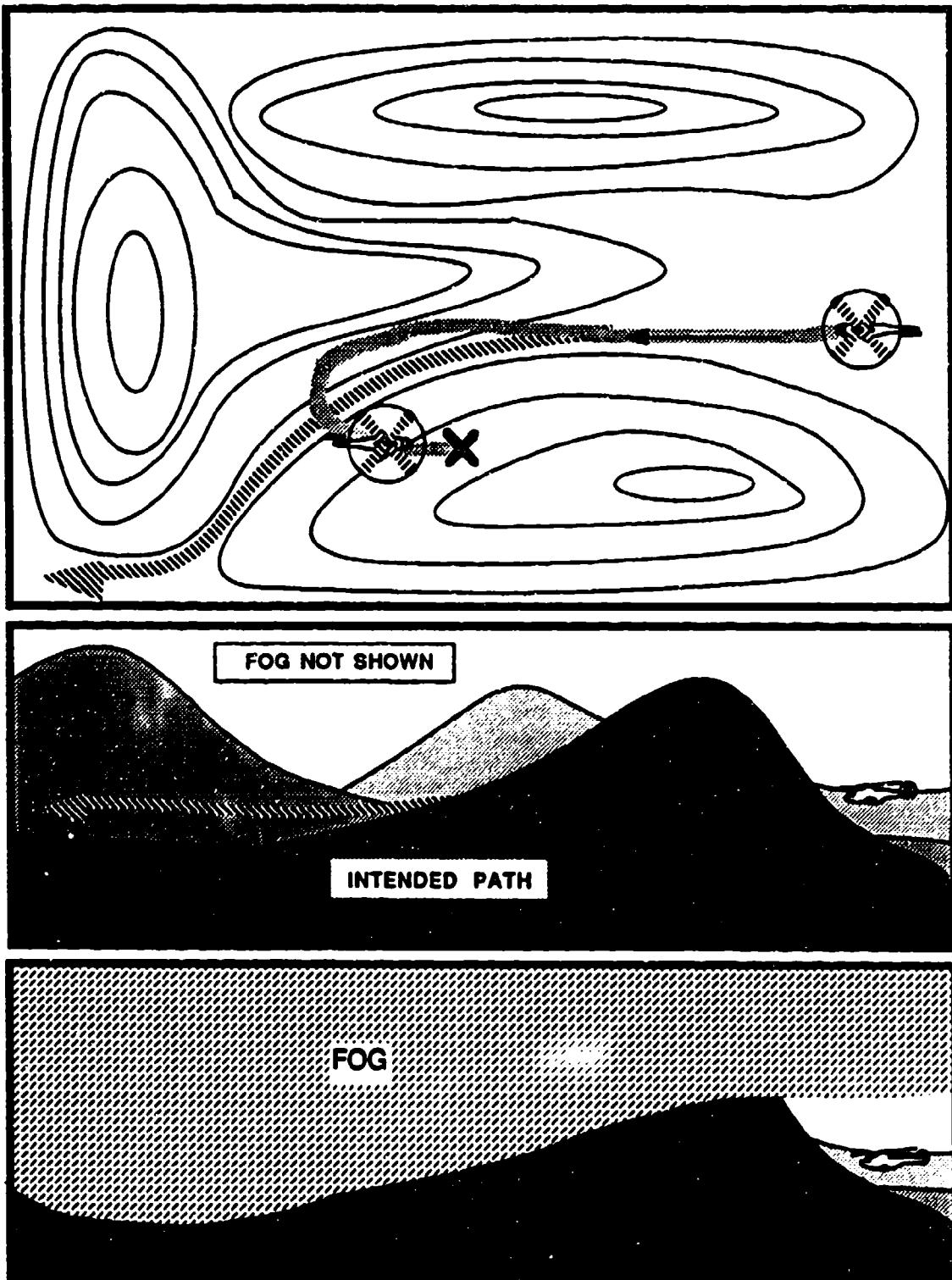


FIGURE 7-12. REVERSE COURSE INTO UP-SLOPE

There is no question that electronic stability and control augmentation equipment can dramatically improve the slow speed handling qualities of the helicopter. But even with the best of these systems, pilots must have an indication of ground speed before they can command the near vertical descent required to avoid flying into an obstruction during the return to visual contact when the visibility is near zero-zero. These systems are not found in normal commercial helicopters because of their limited utility and high cost. Therefore even the best qualified pilot, flying the best aircraft available, will avoid flying into a low overcast or fog bank.

The analysis suggests that if for any reason the environment will not support operations at 60 knots and 200 feet AGL, the flight should be immediately terminated until the weather improves. Over an unfamiliar route this operating condition should be treated as an emergency, just like a transmission chip light or an engine fire warning light.



FIGURE 7-13. CONTINUED FLIGHT DEEP IN MICRO TERRAIN

OBSERVATIONS AND FINDINGS

- 1) Pilots who operate helicopters under visual conditions in uncontrolled airspace do not have a sure way to estimate the visual range of the environment in which they are flying or about to enter.
- 2) Visual range can be estimated based upon the altitude above the ground and the ability to see over the instrument panel. Most pilots are probably not aware of this possibility.
- 3) If the overcast is at 500 feet or less, helicopter pilots should not fly faster than 60 knots or the best endurance speed, whichever is less.
- 4) If for any reason, either to stay clear of clouds or to see the ground over the nose, the aircraft must be flown down to 200 feet, the flight should be terminated:
 - a. Unless the aircraft is flown over a known route which is free of obstructions above 50 feet or,
 - b. Visibility along the flight path is not impaired by rain, fog, haze or other obscuration effect, reducing visibility below 1 mile and,
 - c. The local weather has been reported to be 1 mile or greater within the last 30 minutes, or
 - d. The aircraft is equipped with a device (possibly electro-optical) which provides a continuous and positive indication of visual range.
- 5) Helicopters which are flown over water or through mountainous terrain should incorporate a radar altimeter. The radar altimeter should incorporate an aural warning. The warning should be set at or above 200 feet.
- 6) Pilots turn into their blind side when they intend to reference cockpit instruments employing an eyes-in/eyes-out scanning strategy.
- 7) Pilots turn away from their blind side to minimize the time to regain good visual conditions when they are basing continued flight on VMC control and eyes-out scanning techniques.

SECTION 8

NIGHT VISUAL EN ROUTE OPERATIONS

NIGHT EN ROUTE: OVERVIEW

As observed earlier in references 1 and 5 and the accident analysis efforts of this study, accidents which occurred during night en route operations often stem from unexpected encounters with adverse environmental factors (weather) which reduce the en route ceilings, visibility, or both. Adverse weather caused pilots to change the route, altitude, or both. This is the same basic situation that occurred during day en route operations but there are some important differences. One major difference involves the use of lights. Pilots often used spotlights or landing lights to see-to-navigate at night. In some cases pilots may have used lights to obtain the attitude and motion cues needed to fly the aircraft, but this has not been documented.

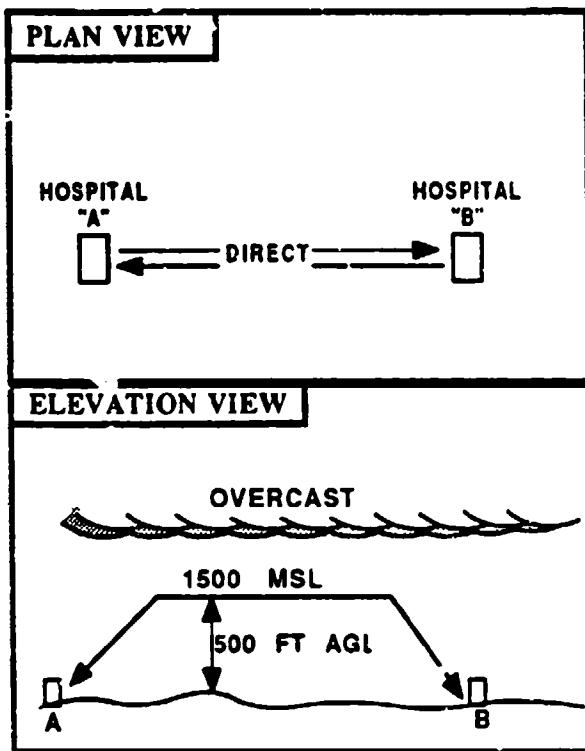
EN ROUTE, DIRECT (NIGHT) SCENARIO (8A)

A single pilot flew the aircraft outbound from one hospital to another using a direct route and constant pressure altitude with a minimum altitude AGL of about 1,000 feet, remaining well clear of clouds. On the return flight, the pilot attempted to return direct at roughly the same pressure altitude used during the outbound leg. After takeoff, the pilot determined that a direct route was not achievable and descended, turning the aircraft away from the planned route numerous times, following known alternative route features such as highways and rivers to circumvent the weather. As the flight drew closer to its original point of departure (which had, up to this point, been supported by terrain features and instrument navigation). The pilot continued descending to stay clear of the clouds and maintain visual contact with the terrain. The pilot was now attempting to follow a heading and an unknown, definable route. In a macro navigation sense, the pilot was attempting to fly a direct line to the destination, not knowing what this meant in terms of obstructions. Eventually the flight encountered an undetected up-slope under a descending overcast. The pilot flew closer to the terrain to maintain visual contact with the trees, but soon struck trees (figure 8-1). A passenger observed a tree passing by the aircraft just prior to the first tree strike. The aircraft was equipped with a good area navigation system and a nominally competent crew.

ANALYSIS

The pilot crew elected to circumvent the weather and finally became involved in a descending ceiling or an undetected up-slope. The pilot reduced his navigation workload by flying heading only, but at the point of contact the speed of the aircraft was excessive for the available visibility. The speed may have been high in consideration of flying qualities. Since the tree was directly in the flight path, cockpit visibility and/or forward-downward illumination may have contributed (see scenario 8C).

FLIGHT AS PLANNED



FLIGHT AS FLOWN

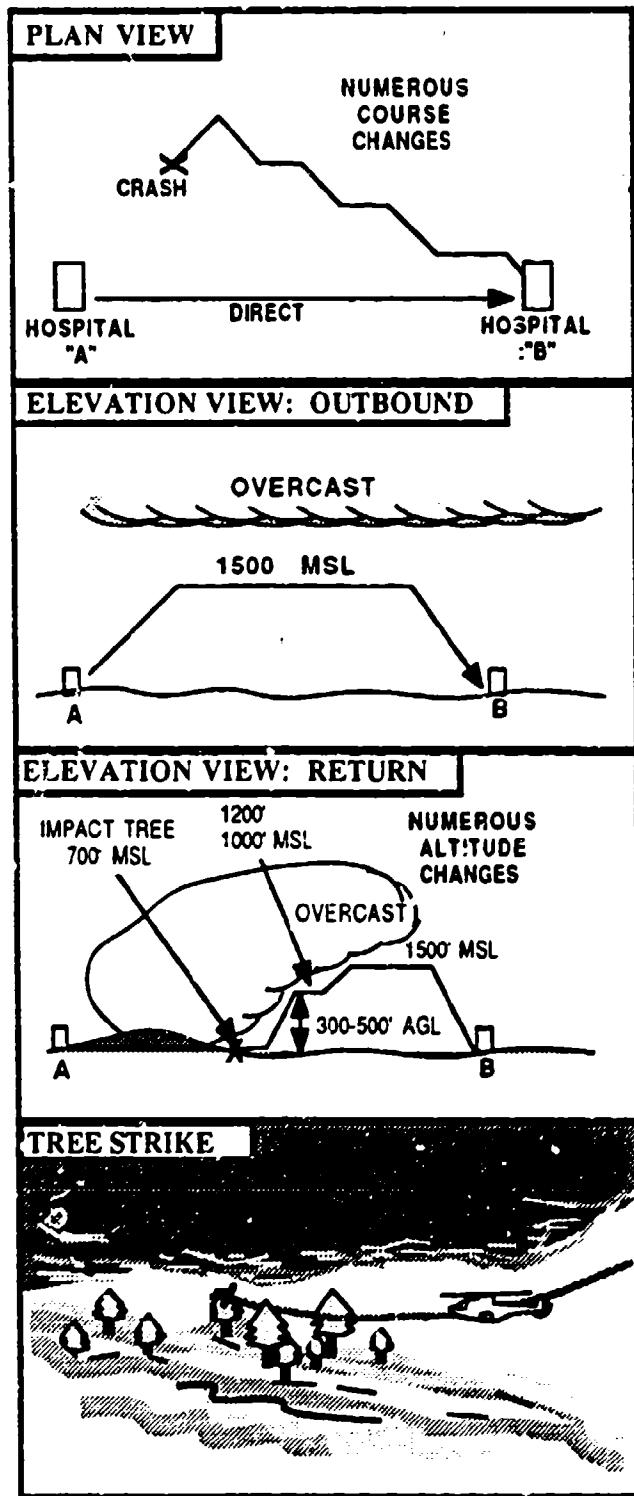


FIGURE 8-1. EN ROUTE, DIRECT (NIGHT) SCENARIO

ROAD FOLLOWING (NIGHT) SCENARIO (8B)

The pilot followed a planned route, returning to base under a thick overcast in a metropolitan area with many surface lights. The visibility became very bad. The pilot slowed and descended, using his spotlight to observe the highway below. The pilot was looking down at the spotlight on the road (see figure 8-2). The passenger hit the pilot on the arm and pointed at the wire ahead. The pilot was unable to avoid the wire. The pilot flew this route regularly and was familiar with the wire he hit.

ANALYSIS

While some of the accidents used to construct this scenario probably involved reckless disregard for flight safety, a number involved an important misuse of lights. As in this scenario, many pilots turned landing lights or spotlights on to facilitate micro navigation. They were then forced to descend to shorten the distance to the ground so that the light could effectively illuminate the surface. But they did not appreciate how low they were, probably because they were spending too much of their

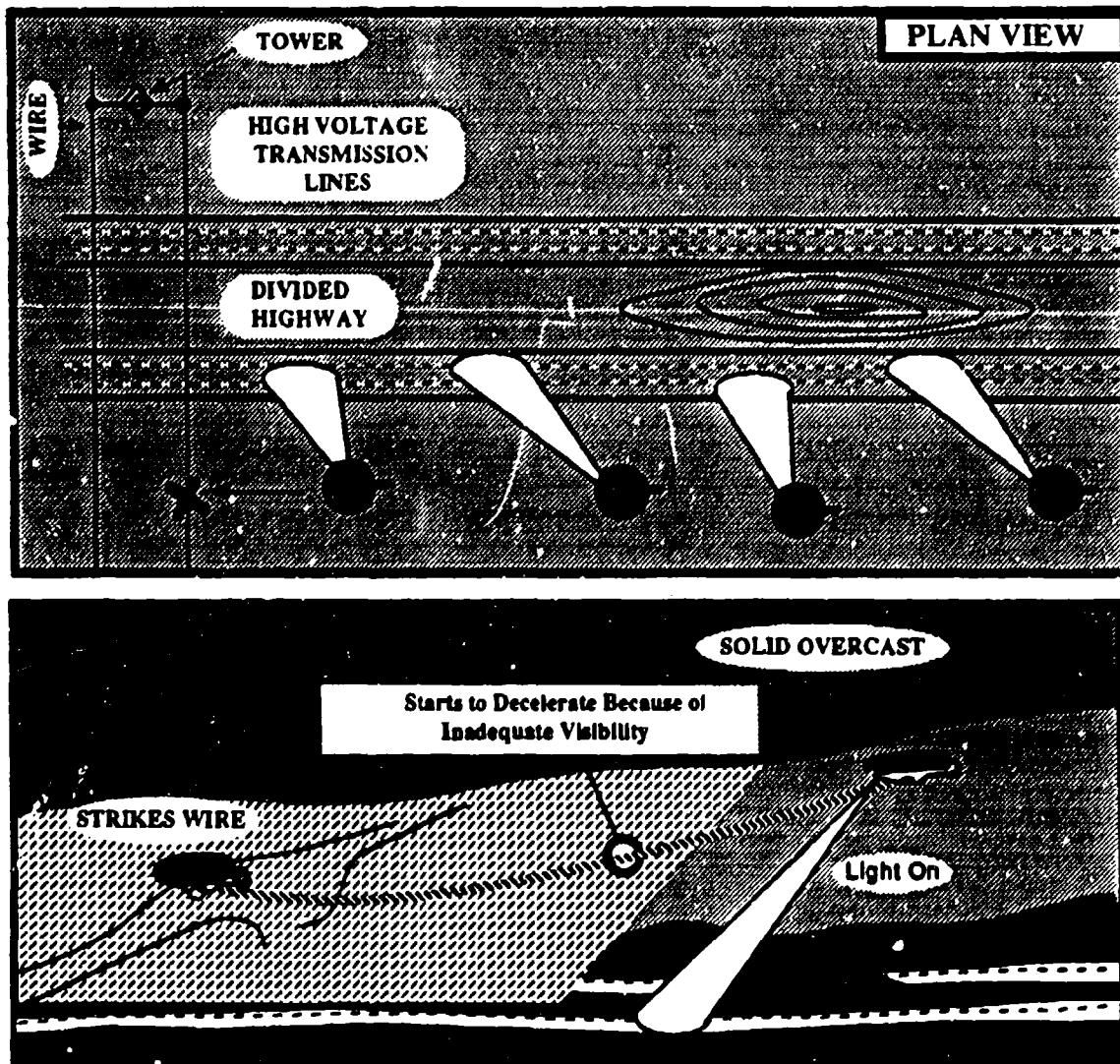


FIGURE 8-2. ROAD FOLLOWING (NIGHT) SCENARIO

scan time looking down at the terrain below them (to follow a road) and failed to apportion sufficient time to the task of checking their flight path. The pilot in this scenario could have seen and avoided the wire if he had been looking forward.

POWER LINE FOLLOWING (NIGHT) SCENARIO (8C)

The pilot started out following a familiar route involving a power line through a remote area with few if any farm or village lights, under an overcast (no sky lighting). At one point witnesses observed the aircraft and estimated the altitude of the aircraft to be less than the height of the wires. In addition, the landing light (or spotlight) was observed to be alternately turned on and then off as the aircraft progressed. The pilot clearly intended to fly along but above the power line (see figure 8-3), but descended as the flight progressed (see figures 8-4A). Eventually the aircraft flew into the ground either (1) attempting to stay inside of a turn in the power line, or (") after flying under the wires, having failed to execute a timely turn, striking the ground while trying to turn and regain contact with the power line right-of-way (see figure 8-4B). The fatal turning maneuver always involved an up-slope, sometimes a steep up-slope and sometimes progressively lower visibility. In all cases contributing to this scenario, the rotor struck trees and bushes in a way which clearly confirmed that the aircraft was in a steeply banked turn at the point of initial impact.

ANALYSIS

Accepting the fact that the pilot should have turned this flight around, this composite scenario reports several interesting characteristics. First, the pilot was observed to turn the light on and off. Why on and off? Second, the pilot opted to keep the speed up and make a hard low level turn instead of slowing to a hover and landing or proceeding at a much slower speed, consistent with visibility. Why?

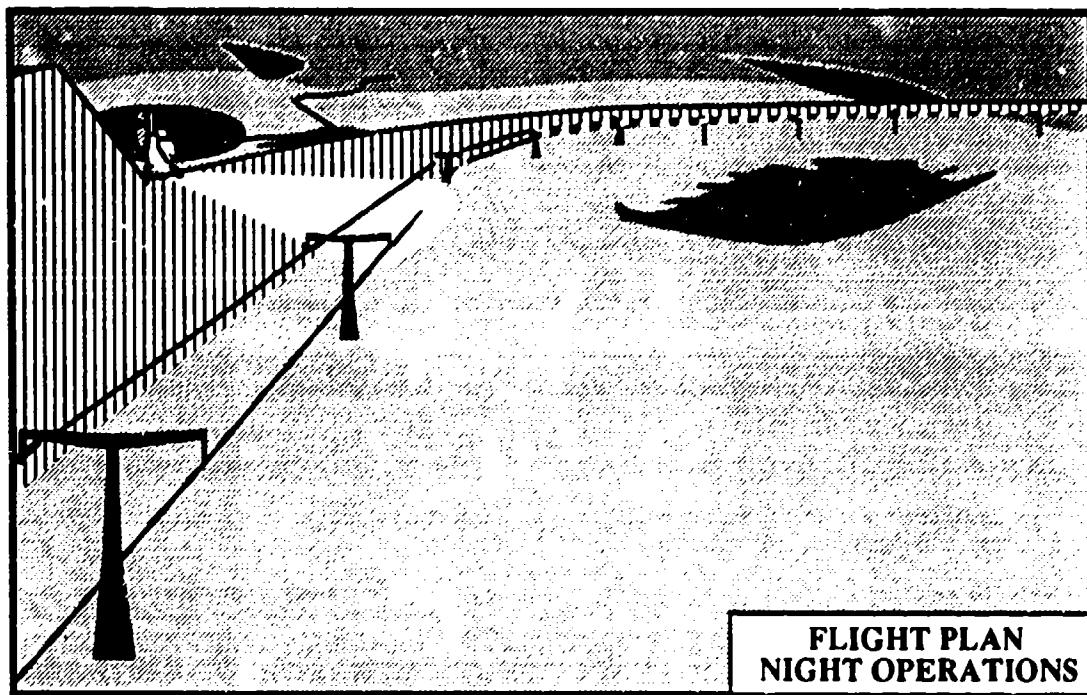


FIGURE 8-3. POWER LINE FOLLOWING (NIGHT) SCENARIO

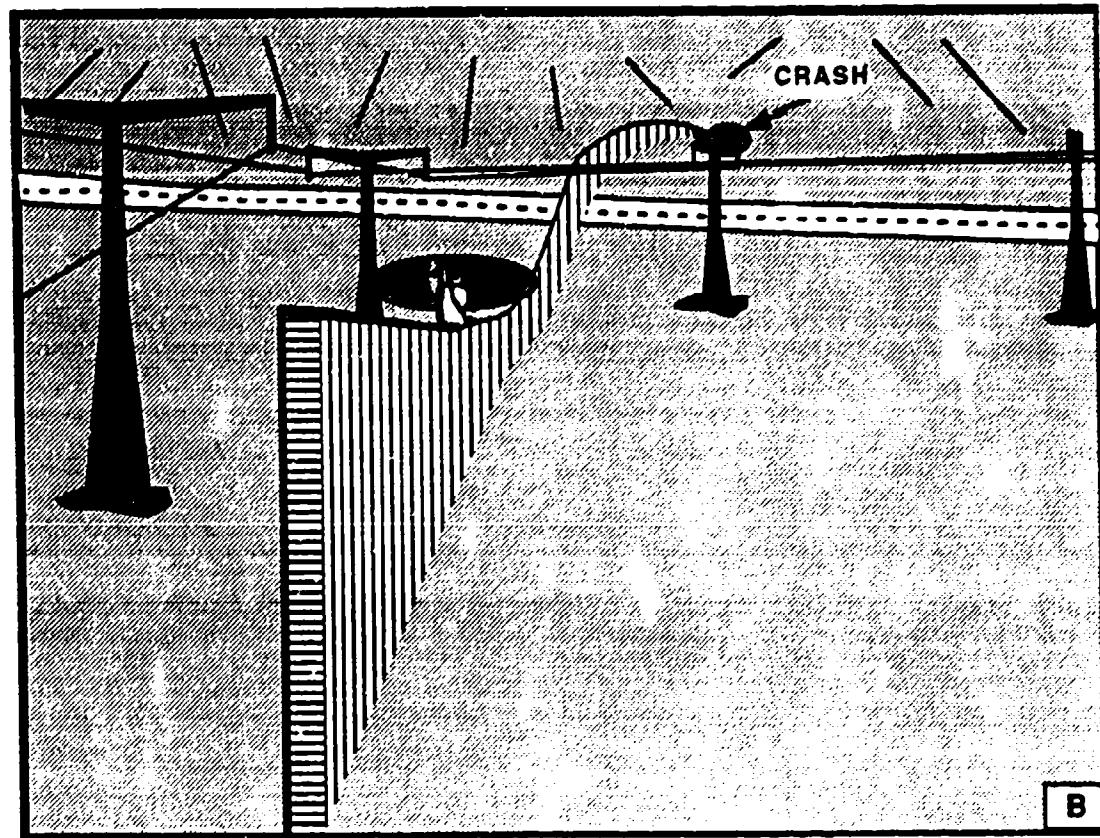
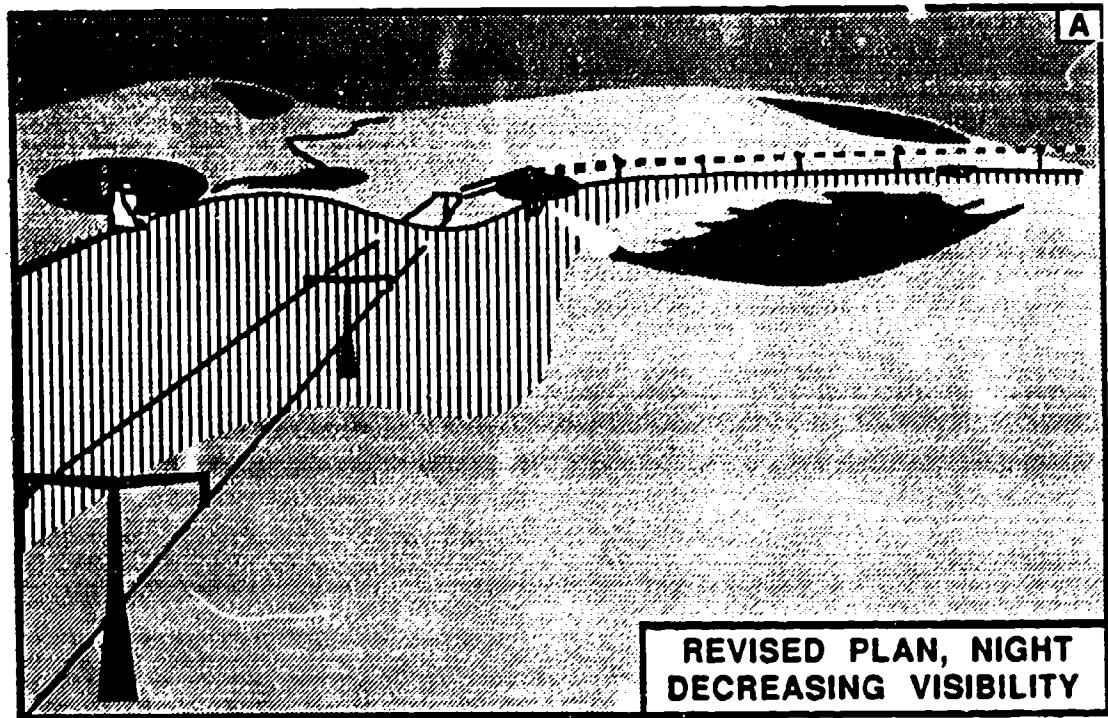


FIGURE 8-4. POWER LINE FOLLOWING (NIGHT) SCENARIO (CONTINUATION)

Pilots will turn spotlights and landing lights on to see the ground when they follow a road, river, power line, or railroad on a dark night. They turn the light off because they also desire to see the horizon and distant lights which are also apart of their visual cue system. Pilots need these distant cues for attitude reference and to have a feeling of well being. As flying qualities degrade, these cues are increasingly important, and flying qualities typically degrade significantly as speed decreases below about 50 knots. The light which is pointed downward will often produce backscatter which in turn will partially or totally obscure the distant visual cue system. Backscatter typically becomes an increasingly debilitating factor as the dust and moisture content of the air increases.

Now consider figure 8-5 which explores the use of a forward looking light while following a road or power line. The light is shown pointed forward of the aircraft and down so that it can be seen just over the instrument panel. As the visual range of the light is degraded by moisture or dust, the altitude must be decreased to continue to see the ground. The nose attitude of most helicopters is increasingly nose up as the aircraft slows down to about 40 knots (or 68 feet/sec). At this speed the aircraft may even be flying nose up. In any event, the pilot is typically able to see roughly 300 feet (slant range) if the aircraft is flown down to an altitude of about 100 feet AGL. This range provides the pilot with about 4 seconds to detect and execute a maneuver to avoid. It is reasonable to expect that most single-engine helicopters will not be able to change altitude more than about 60 feet during this period (the actual achievable altitude change may be as small as 20 feet). Neither will it be able to stop in the available space, nor can a turn-to-avoid be accomplished.

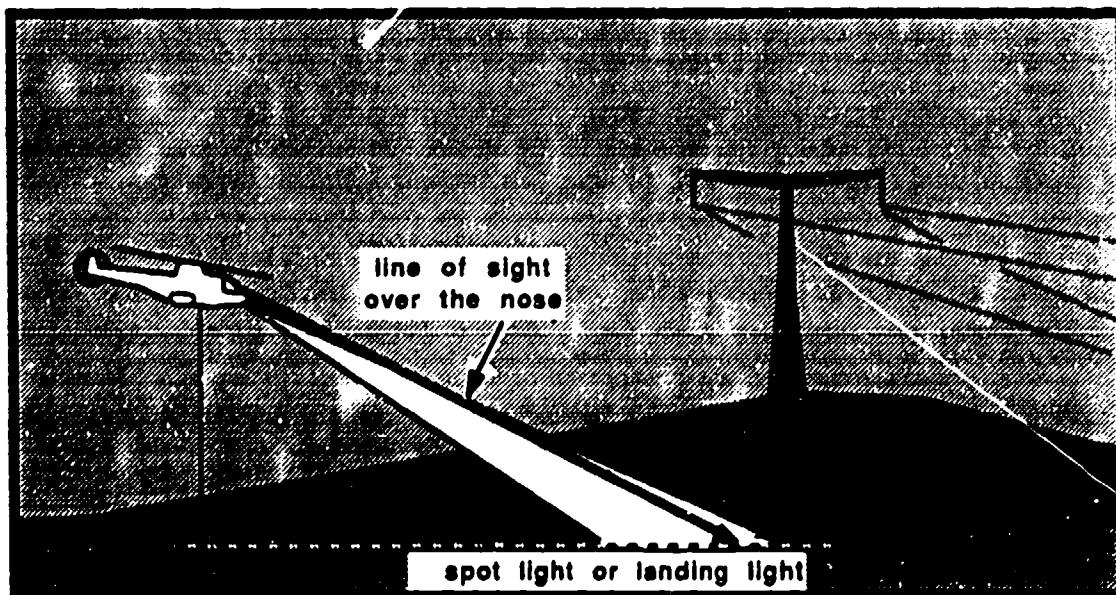


FIGURE 8-5. LIMITATION OF LANDING LIGHTS FOR OBSTRUCTION DETECTION

This analysis indicates that a modern civil helicopter should not proceed faster than about 20 or 30 knots when below 200 feet and in the obstruction (wire) rich environment at night. It also suggests that at least one light is required to look

forward along the flight path when descending to land and another should be strong enough to provide a pilot with useful micro navigation cues at or above 200 feet AGL.

To summarize, pilots are reluctant to slow down because of flying qualities factors. They turn lights on to see and monitor their path over the ground, and they turn them off to see the cues they need to control the aircraft.

Collectively the preceding accepts, as a fact, that a pilot can be expected to sometimes become involved in a sudden and unforecast encounter with a low visual range environment. This can happen because the pilot is often unable to detect such degraded environments prior to encounter. A sensor which looked ahead and warned the pilot of low visibility ahead would then appear to be an extremely useful device. It would allow the pilot to turn around before becoming involved in a low visibility environment. The above also confirms the need for a good look-forward and look-down light system which has been designed and installed in a way which minimizes backscatter. The installation of a radar altimeter with a low altitude warning feature would alert pilots who inadvertently descend below 200 feet and approach the obstruction rich environment below about 100 feet.

SLOW SPEED DISORIENTATION (NIGHT) SCENARIO (8D)

The pilot diverted from the planned route to proceed directly to the destination. The route followed resulted in lower and lower ceilings. The pilot was observed to use a spotlight from time-to-time as illustrated in figure 8-6. While operating with the light on, the aircraft flew into a fog (or snow) type obscuration. The light was diffused by the obscuration and the pilot turned it off. The pilot was observed to pull up slightly, decelerating while climbing. Next the pilot was observed to be "working very hard" to control the aircraft. The aircraft crashed in a steep nose down attitude, with little or no horizontal motion at the time of impact.

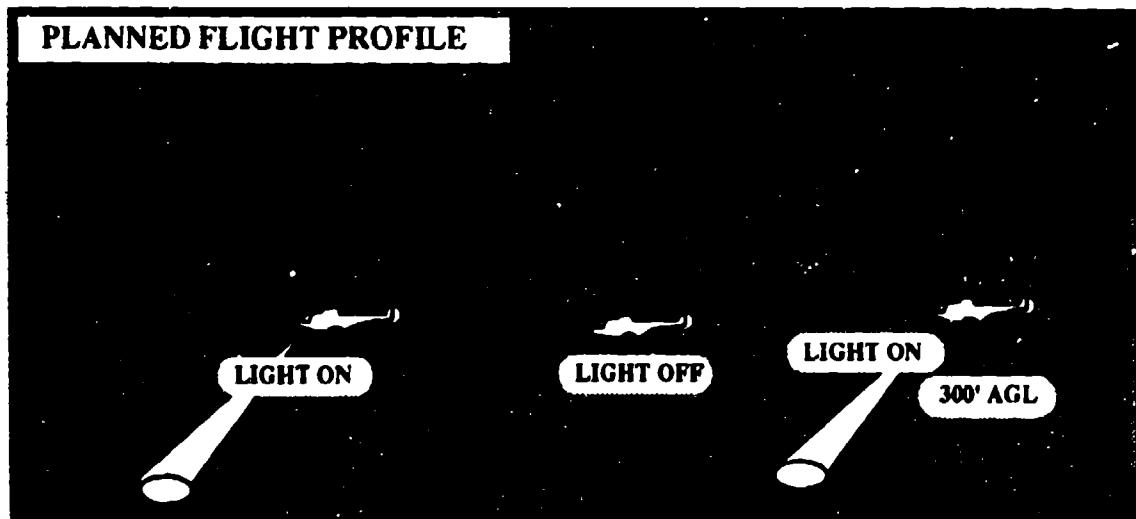


FIGURE 8-6. SLOW SPEED DISORIENTATION (NIGHT) SCENARIO

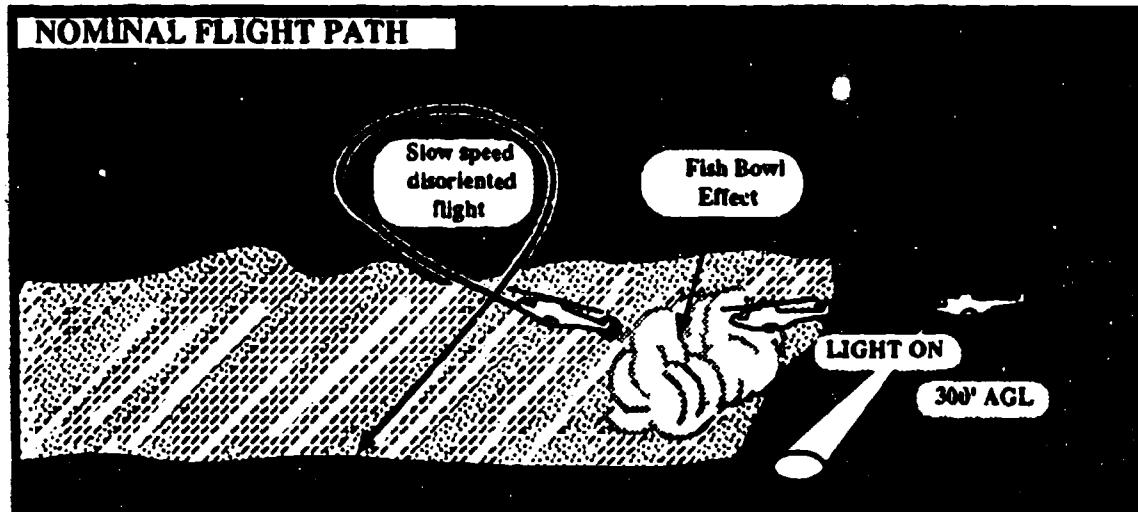


FIGURE 8-7. RECONSTRUCTION OF SLOW SPEED DISORIENTATION (NIGHT) SCENARIO

ANALYSIS

In this case, the pilot was observed to pull up and decelerate as reflected in figure 8-7. The aircraft then became very difficult to fly. These events translate into a full power climbing deceleration which probably involved a moderate nose up attitude. This entry and resulting condition have been observed during slow speed helicopter stability and control flight testing. The typical result is an eventual heading reversal, similar to a "hammer-head stall" in an airplane. That is, the helicopter is actually accelerating into rearward flight at the top of the maneuver, and weather-cocks into the relative air mass after the pilot finally loses heading control (figure 8-8). These maneuvers were observed during the testing which was conducted to examine service suitability of military helicopters leading to the establishment of the test techniques included in reference 35. The product of such a maneuver is consistent with the crash remains and the observations of survivors reported in the accident reports analyzed during this study.

This composite profile reflects the need for much better equipped aircraft and better trained pilots. The pilot was obviously not prepared to fly the aircraft if it encountered IMC conditions. In such cases, it seems logical to equip and crew the aircraft for IFR operations or equip the aircraft with an IMC detection sensor (probably a derivative of existing electro-optic equipment).

SUMMARY OF SECTION

The avoidance of obstructions under the conditions discussed above represents a consideration of flight safety after the aircraft has descended deep into the obstruction environment. While this is important, it is even more important to understand that all of these accidents could have been avoided if the aircraft had:

- remained at altitude, above the obstructions, and
- had avoided encounters with IMC conditions.

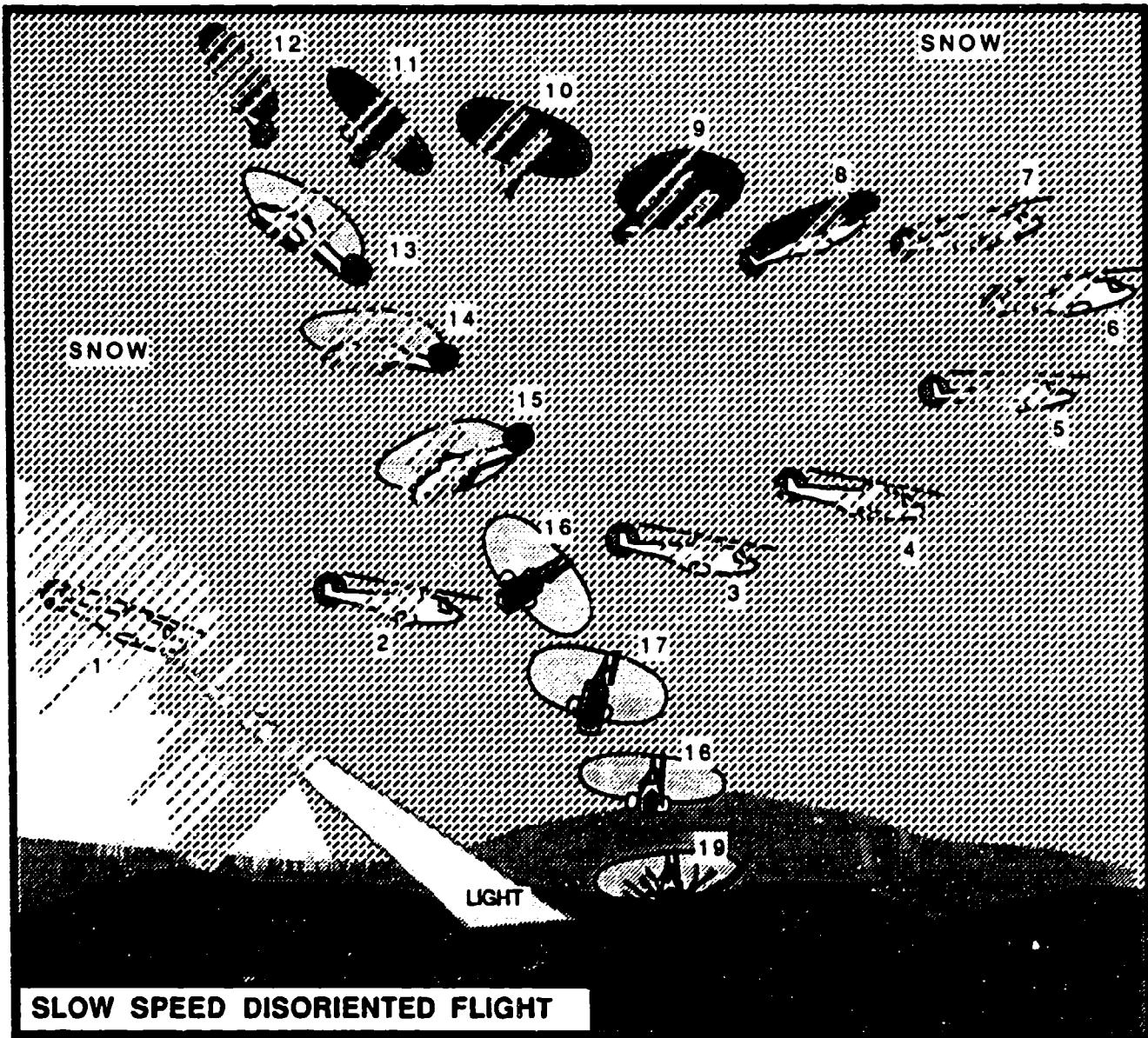


FIGURE 8-8. ANALYSIS OF SLOW SPEED DISORIENTATION

The following recognizes the preceding need and includes concepts that characterize one approach to systematically improving safety during flight operations conducted in uncontrolled airspace under DVC. This approach is presented here to help the reader understand the need, not as a recommended best solution.---A routing system could be developed for each operating region. Operating criteria would be modeled after reference 3 and employed in conjunction with regional helicopter route charts (similar to reference 36) tied to electronic and terrain-based data. Advanced navigation techniques (for example LORAN-C and GPS) would be used to provide redundant low altitude navigation signals and advanced vision systems will enhance situational awareness. The integrated product would yield an affordable and safe en route traffic management methodology uniquely suitable for rotorcraft operations during DVC in uncontrolled airspace. This methodology would utilize advanced

communications equipments, suitable for low altitude operations. This will allow pilots to report adverse weather and request an orderly transition into the lower levels of the controlled airspace when IMC is approached (but never entered), or alternately the aircraft will be able to proceed in a rational way to predesignated landing sites. The aircraft could be equipped with a device which allows the aircraft to see-and-avoid environments which involve unacceptably low visual ranges. The aircraft would have flying qualities which are adequate to support DVC flight operations down to some minimum speed (some aircraft will be qualified to hover under DVC, others will not). Finally, a training pamphlet, similar to reference 32 could be developed to help inform pilots as to the unique aspects of night flying, including night adaptation and illusions which helicopter pilots can expect to encounter.

OBSERVATIONS AND FINDINGS

The "highway following" and "power line following" accidents are both the result of poor pilot judgment. Nevertheless, the pilot could probably have averted these accidents by decelerating to a hover and landing when the visual range became intolerably short. Additionally, these accidents probably could have been averted if:

- 1) a visual range sensor had been installed to warn the pilot that an area of degraded visibility would soon be encountered (in the case of a sudden and unforecast encounter with a low visual range environment), and had the pilot then turned around at the time of warning;
- 2) while attempting to reverse course at a safe altitude, a radar altimeter had been installed and the pilot had observed a minimum AGL altitude of 200 feet or more, and a aural low airspeed warning had been installed, to alert pilots of unintentional low speed operations below the equivalent of V_{min} ;
- 3) a powerful spotlight had been installed (with sufficient useful range to support micro navigation at or above 200 feet AGL) then the pilot could have:
 - a. followed the route at a safe altitude,
 - b. returned to the departure point at a safe altitude, or
 - c. flown to a safe immediate landing spot without the need to descend into the obstruction rich environment below 100 feet to find such a spot; or
- 4) the pilot had been confident enough of the aircraft's slow speed performance and flying qualities to slow down to 20 or 30 knots during the process of finding a landing location.

In the future, a routing system could be developed for each operating area. Procedures might be modeled after reference 3 and employed in conjunction with regional helicopter route charts, similar to reference 36. Other features might include:

- 1) advanced navigation techniques (for example LORAN-C and GPS);
- 2) advanced vision systems;
- 3) advanced communications equipments, suitable for low altitude operations;
- 4) equipment and flying qualities to support slow speed and hovering operations under difficult visual conditions; and
- 5) aircraft equipment to allow pilots to detect and avoid the near approach of unacceptable visual environment.

SECTION 9

CIRCLING APPROACH TO REMOTE SITE

REMOTE SITE (NIGHT) SCENARIO (9A)

This composite accident involves an approach to a remote, undeveloped landing site. The pilot was asked to land at a clearing in a heavy forest to respond to an emergency situation.

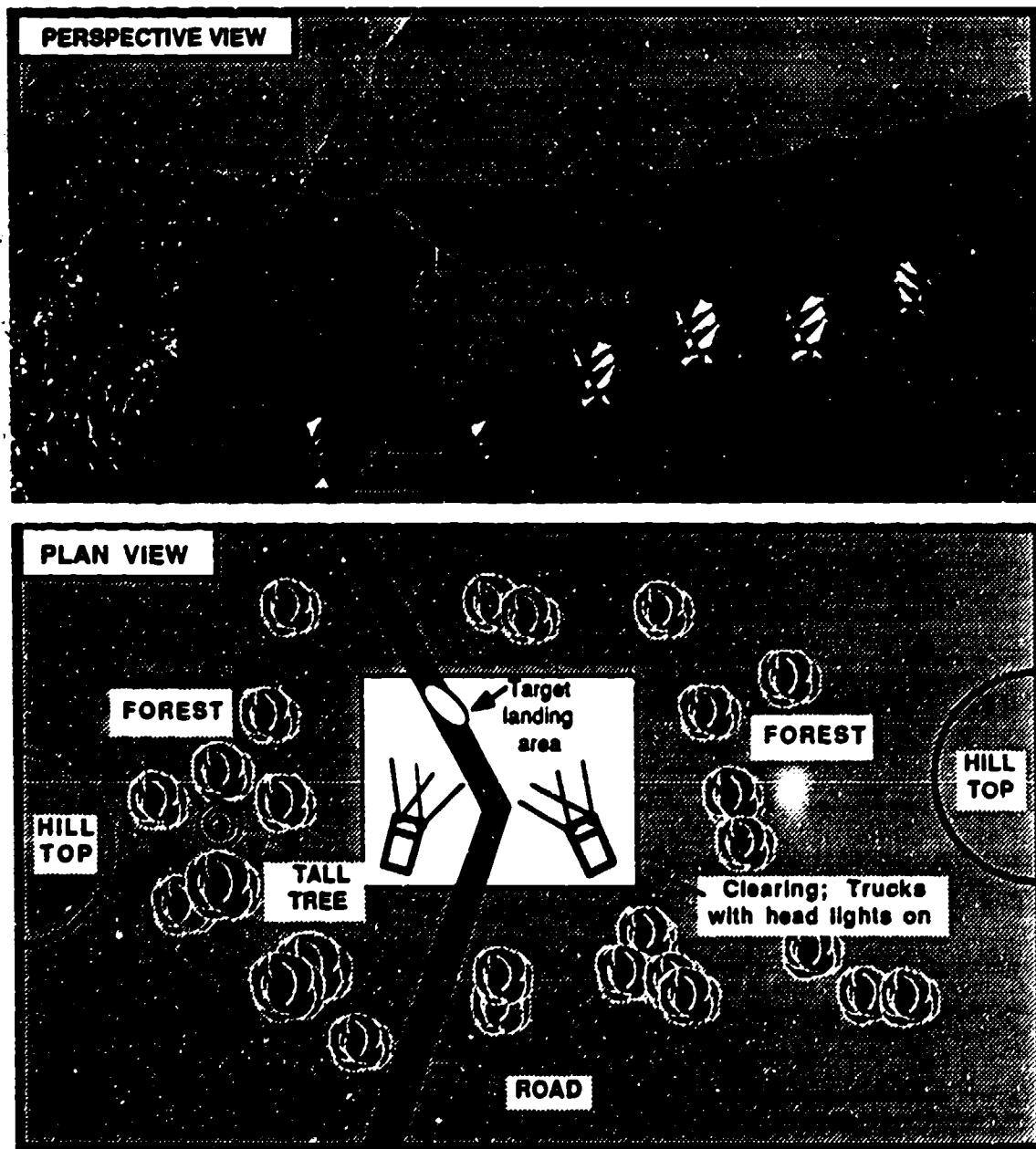


FIGURE 9-1. REMOTE LANDING SITE

The pilot conducted a circling descending turn to the right to accomplish a pre-landing reconnaissance. Everything was conducted in a safe and logical way until the pilot stopped turning to the right. The pilot reversed the turn to the left, in an apparent attempt to fly a left downwind and start the approach to a hover. During the turn downwind, the aircraft struck a single, uniquely tall tree on the ridge adjacent to the objective landing area.

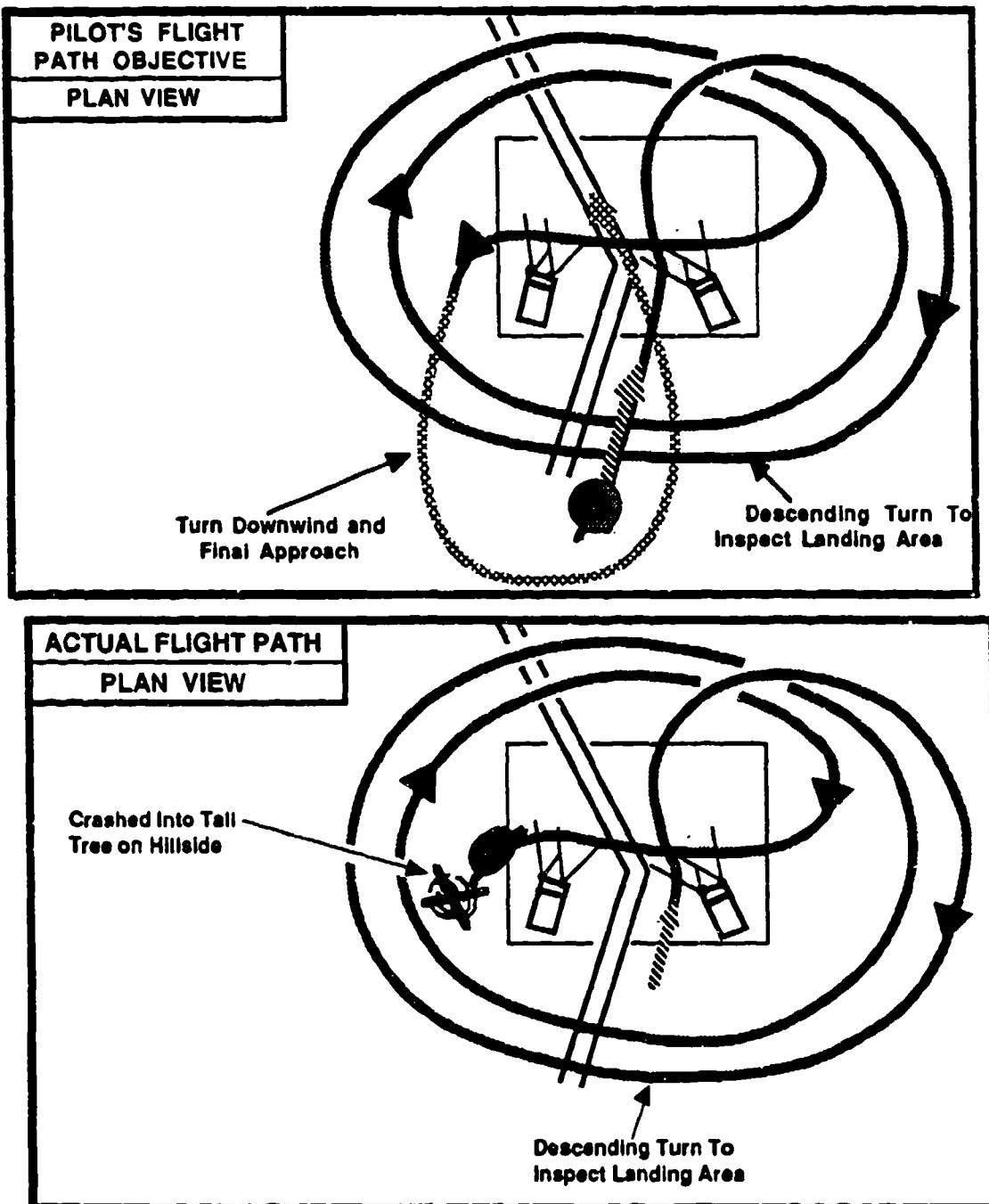


FIGURE 9-2. CIRCLING DESCENDING APPROACH TO CONTAINED SITE ANALYSIS

The important analytical points are:

- the pilot reversed his turn overhead,
- the pilot turned into the blind side of the aircraft (single pilot, eyes-in, instrument flight techniques),
- there was no radar altimeter, and
- a tall tree went undetected during an otherwise proper descending reconnaissance (the height of the ridge was underestimated).

The pilot was in the right seat and conducted the area reconnaissance while banked to the right in a series of right turns.

The pilot crashed into a tall tree, which may have been on an undetected ridge, while turning to the blind side. The crash occurred just after the pilot initiated a major change in piloting technique. Pilots should be alert to avoid such technique changes near the surface.

When the pilot elected to descend for the final approach, he turned left. This may have been because this was the direction which would yield the shortest path to reach the final straight in approach point (into the wind). In addition, it allowed the pilot to look through the cockpit, and over the instrument panel. As discussed earlier, this would have allowed this pilot to scan the instruments during the turn-descent, but it also decreases the pilot's ability to see obstructions. The cockpit frame is in the way.

In this case, the task of reorienting the searchlight may have distracted the pilot, detracting from the instrument scan. (Note: The pilot may have also assigned priority, within the instrument scan task, to the performance instruments: speed, power, rate-of-climb/ descent, altitude, etc.)

A radar altimeter (with aural warning) and suitable procedures would probably have precluded this accident and others like it. The altimeter should have an audio warning feature set to activate at a minimum of 200 feet. This aural requirement recognizes the pilot's need to fly heads-up, eyes-out during the reconnaissance and approach.

The pilot may have also been behind in reorienting the landing light/searchlight/spotlight from the right side and down, to ahead and left. This sort of data was not available, but experience has shown that this does take time and it does involve workload. The workload associated with the spotlight was also noted in an earlier night vision operations study which also observed that the field-of-view of head mounted sensors (such as night vision goggles) moved rapidly to the desired location. The head mounted devices were found to be much quicker and operate with greater precision and with less effort than was required with a electrically controlled light.

In summary, the pilot should not have descended below 300 feet AGL until the aircraft was on its final heading. The pilot should have stayed at altitude until on final to avoid obstructions. When on final the pilot should have decelerated to a low but safe speed, say 40 knots airspeed, and conducted a steep approach to minimize the horizontal exposure to obstruction. This would have allowed the aircraft to decelerate to a position which would have allowed a steep final descent while observing the guidelines established by the HV diagram.

OBSERVATIONS AND FINDINGS

Safe approaches to a confined remote area at night require the best possible reconnaissance before descending and good procedures during the descent to landing. The initial reconnaissance should probably be conducted from not less than 500 feet AGL followed by a low reconnaissance at not less than 300 feet. Both of these altitudes should be observed via reference to a radar altimeter.

Hover floodlights should be installed and operating when aircraft are flown at night into remote landing sites which may involve obstructions along the approach path. This will permit at least one light to be oriented along the approach path while the floodlight illuminates the landing area.

The limitations associated with the lights available today suggest that there is a need for improvement. This could include the addition of sensors which can operate in conjunction with and augment the current white lights.

The aircraft should not descend below a safe obstruction avoidance altitude (say 200 feet AGL) until the aircraft is established on a straight-in final and the speed has been reduced to the slowest value which is also safe for the altitude and performance considerations during final approach to a high hover.

The final descent speed should allow the pilot to approach the high hover position without overflying the pilot's ability to see-and-avoid wires.

The pre-landing hover should allow a performance check before descending into the landing area. The hover should be as high as 200 feet AGL if the limitations of the aircraft permit.

SECTION 10

DECELERATIONS INTO OBSTRUCTIONS

STEEP APPROACH SCENARIO (10A)

The pilot arrived at an unfamiliar location and executed an approach to a parking lot to pick up a passenger. Observing the wind line, the pilot elected to descend along the contour of a nearby hill (see figure 10-1).

On the final segment of the approach, the aircraft struck a power line running perpendicular to the approach path. The pilot had observed the wire but misjudged the position of the aircraft on final.

ANALYSIS

The approach, viewed over the nose always appears steeper than it really is. A 10 degree approach can appear to be almost vertical. This is a form of optical illusion. The look down capability on a truly steep approach is further degraded during the deceleration.

This characteristic may also be significant during the visual segment of a steep instrument approach. The ability of the pilot to see down through his feet seems to ameliorate this characteristic once the pilot learns how to use this approach technique.

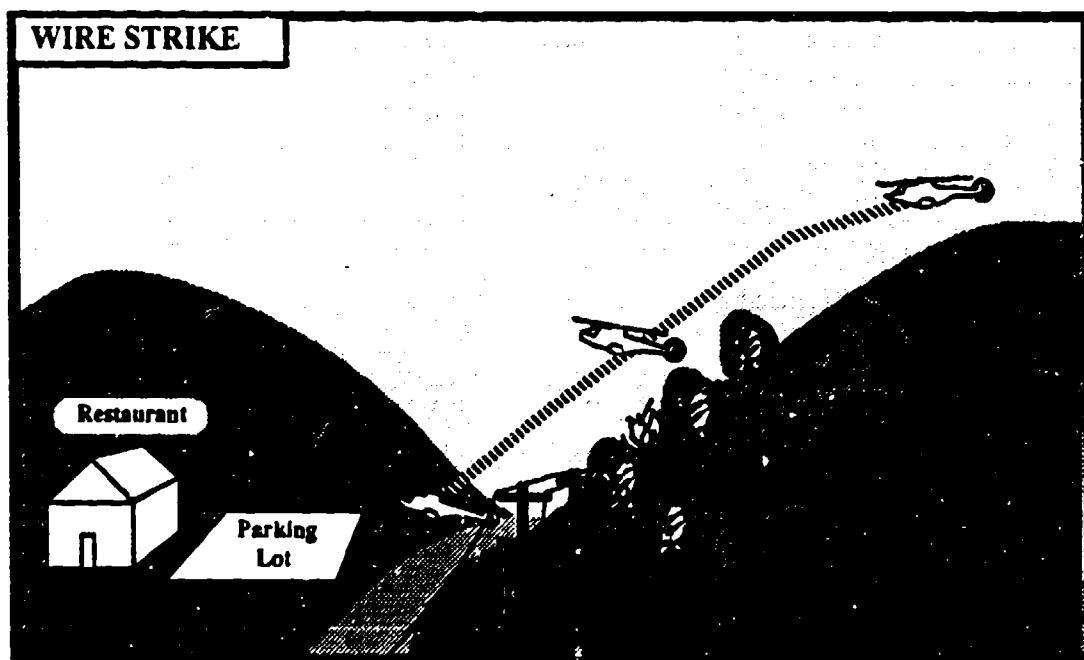


FIGURE 10-1. STEEP APPROACH INTO WIRE ON APPROACH TO CONFINED AREA

HIGH SPEED DECELERATION DOWN SLOPE SCENARIO (10B)

The pilot took off from the mountain operating site and proceeded to fly down slope. The flight was conducted close to the terrain to remain visual beneath an overcast which followed the contours of the mountain. The pilot observed that the aircraft was accelerating to an undesirably high speed and initiated a deceleration. The tail of the aircraft struck the terrain during the deceleration maneuver and the aircraft crashed.

ANALYSIS

The natural tendency to slow down and fly down, discussed earlier, is involved here as well. Pilots who have not had a similar experience do not anticipate it. The departure (nose down) is easy but very quickly, the aircraft is going too fast. The slope of the terrain, the overcast and the obscuration all complicate the deceleration task.

Pilots can become subject to an illusion taking off down slope under a low overcast. The tendency is to think the horizon is lower than it really is when using visual cues, heads up and eyes out. This results in a confusingly rapid acceleration down hill which causes the airspeed to build to a value which is too fast for the visibility. [A similar illusion can be experienced while driving an automobile through a mountainous area.]

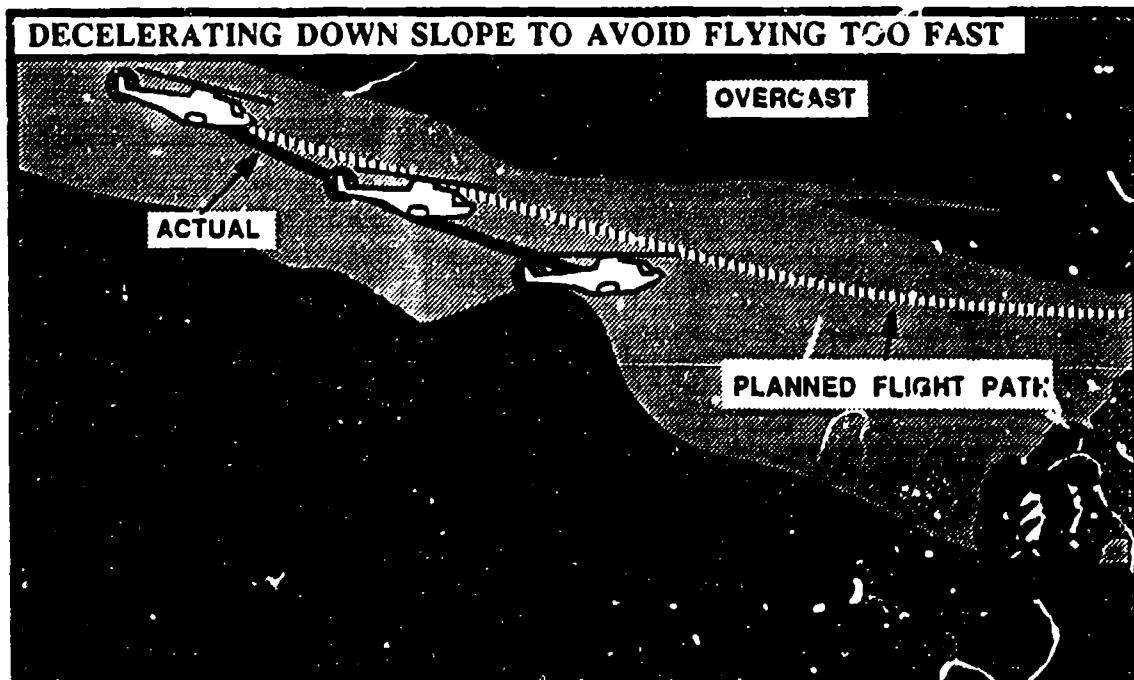


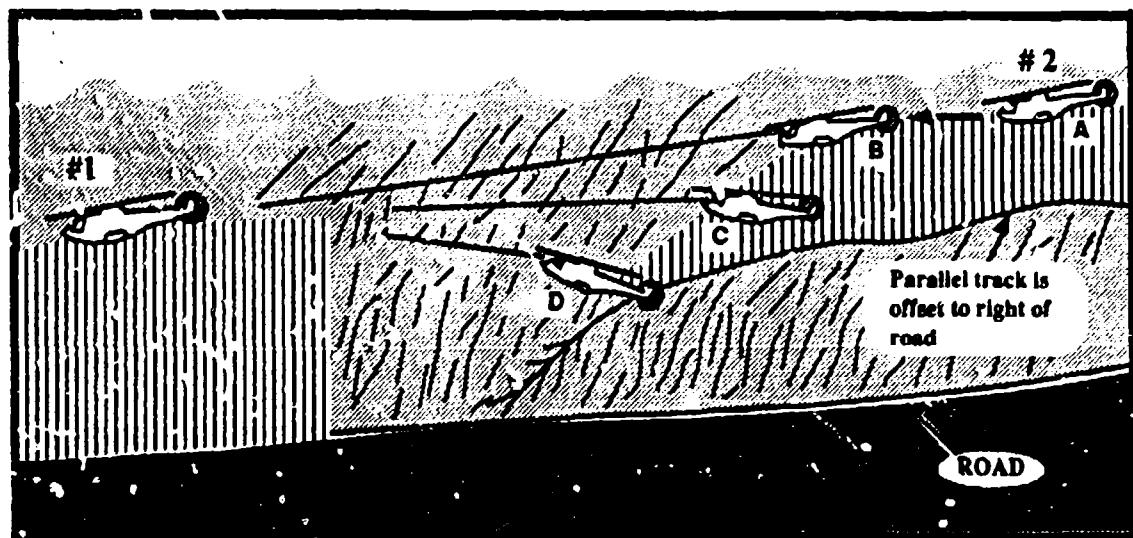
FIGURE 10-2. UNDERSHOOTING INTENDED FLIGHT PATH DURING ATTEMPT TO CONTROL AIRSPEED WHILE FLYING DOWN HILL UNDER OVERCAST

TAIL CHASE SCENARIO (10C)

Two aircraft are returning to the point of origin. The two aircraft were following a road down through a mountain pass. The number two aircraft was reported to have been following about 1 mile behind the lead. As the visibility deteriorated and darkness set in, the pilot of the number two aircraft accelerated to catch up with the lead aircraft so as to maintain a solid line-of-sight. As the number two aircraft approached the number one aircraft, the pilot recognized that he was over running the first aircraft and lowered the collective to decelerate and maintain station. The number two aircraft was displaced to the right of the lead aircraft and in the process, the aircraft descended and contacted the up slope terrain.

ANALYSIS

The trailing aircraft descended in part as the result of the pilot's efforts to maintain line-of-sight with the lead aircraft during deceleration. That is, as the nose came up and the lead aircraft started to disappear below glare shield of the second aircraft. To keep the lead in sight, the second pilot lowered the collective to fly down. This has been observed in a number of accidents and is a natural helicopter piloting response. In addition, the slope down to the left and up to the right may have induced an additional depth perception problem. In any event, the aircraft was under control when it was flown into the ground trying to decelerate.



- A. #2 starts to overrun #1.
- B. Pilot of #2 brings nose up and lowers collective slightly to decelerate. As nose attitude increases, #2 finds it difficult to maintain line-of-sight.
- C. When #2's loses sight of #1 over the glare shield, pilot #2 lowers collective even more.
- D. RESULT: Loss of altitude and ground contact.

FIGURE 10-3. GROUND CONTACT DURING ATTEMPT TO MAINTAIN SAFE DISTANCE

DECELERATION INTO WATER SCENARIO (10D)

The aircraft approached a private landing site on a lake bank. The site was 10 feet above a calm water surface. The pilot approached the site straight in and settled into the water while decelerating. The aircraft was not equipped with a radar altimeter. It was a day operation, but visibility was complicated by a heavy haze.

ANALYSIS

This is one more case of an undetected loss of altitude during a visual deceleration to a hover. The calm water introduced an added problem in that a calm water surface will often meld into the haze and there is essentially no well defined line of demarcation between the water and the sky. A radar altimeter is the only sure way to avoid such an accident.

The pressure altimeter can be used but it has its limits as well, depending upon the aircraft. That is, it is not expected to be accurate at speeds below about 40 knots. There is no recognized need for excellent accuracy on a VFR aircraft. In addition, changing conditions can change the pressure altimeter setting and induce error over time (normally, there is no one at such a site to report the altimeter setting).

One alternative procedure involves an overflight (or fly by) of the landing site to establish a safe pressure altitude before decelerating over water. It would seem prudent to avoid descents below 100 feet (as indicated by the pressure altimeter) during the deceleration. Maybe the aircraft should not descend lower until the platform can be seen below and to the side, well under the aircraft.

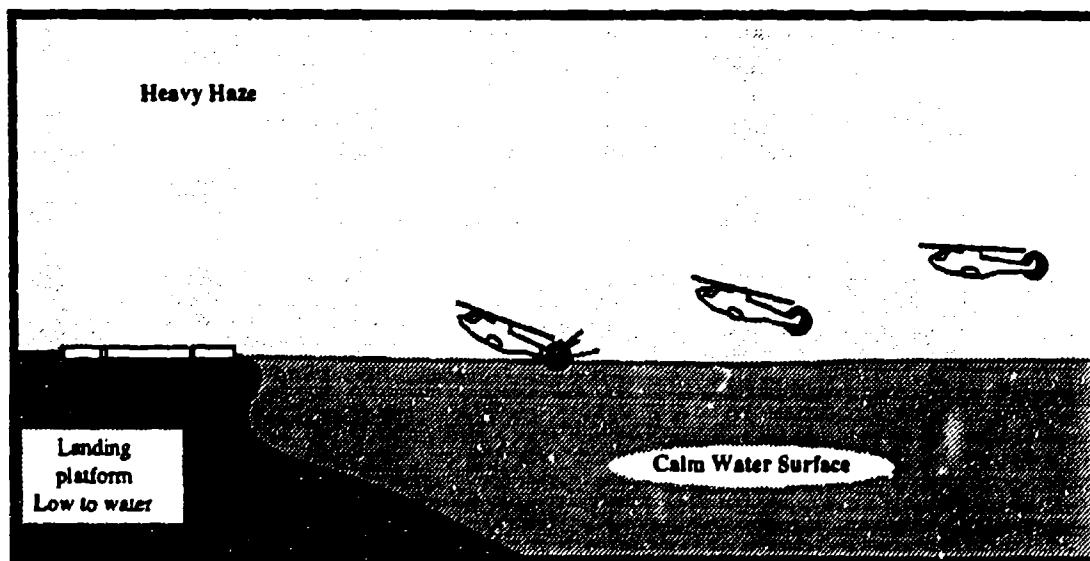


FIGURE 10-4. WATER CONTACT DURING ATTEMPTING TO DECELERATE AND RETAIN VISUAL CONTACT WITH LANDING SITE

DECELERATION INTO WATER SCENARIO (10E)

The aircraft was crossing a large lake under a low hanging overcast (fog). The pilot could see the bank in the distance and had a good horizon but was concerned and elected to slow down and stay below the bottom of the ragged edges of the overcast. As the aircraft decelerated, it struck the water and crashed. The operation was conducted in daylight. A radar altimeter was installed but not noted during the maneuver.

ANALYSIS

The pilot was flying too low. The pilot should have conducted the deceleration, referencing the radar altimeter and pitch attitude indicator. Failure to utilize this sort of technique suggests a lack of appreciation of the need to use instrument flight skills/techniques when flying over water.

It is interesting to observe that flight over large areas of open water are assumed to be obstruction free. This gives some pilots the confidence to descend and fly low over the water on a routine basis. This is illegal (reference 15) and can be extremely dangerous, especially over calm, slick seas and when ships or boats are encountered.

One might conclude that pilots who fly over water need to have instrument flying skills. If they do not, they should not fly over water unless the weather is observed to be sufficient to insure that such skills are not required. That is, if the flight is conducted at a high altitude, under good VMC, the operation can be relaxed.

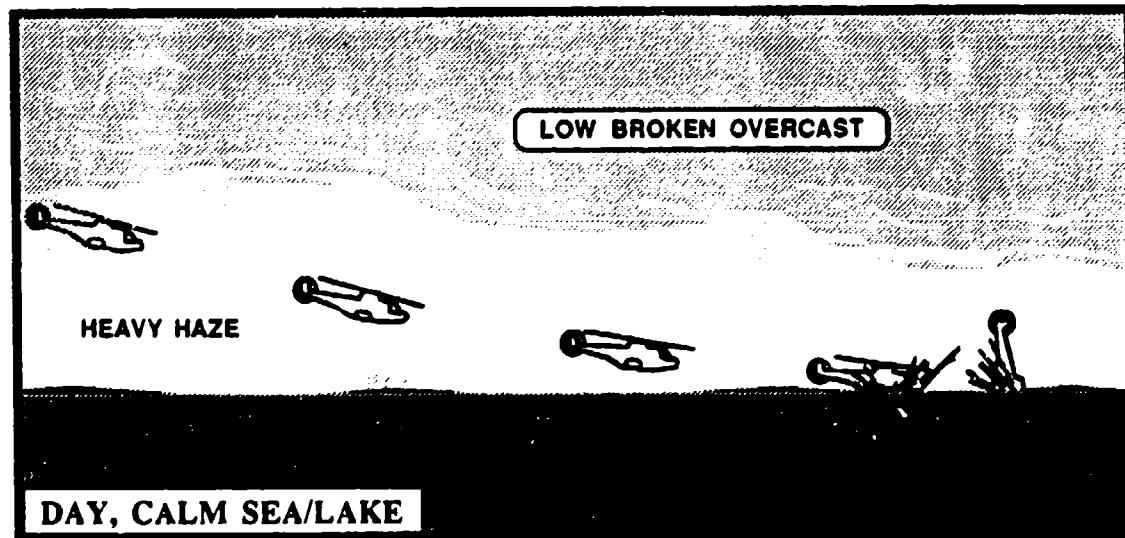


FIGURE 10-5. POOR ALTITUDE CONTROL DURING OPERATIONS OVER SLICK WATER SURFACE, UNDER OVERCAST

OBSERVATIONS AND FINDINGS

The fact that pilots routinely descend into the water, ground, and other obstructions low to the ground while decelerating is important to many operations. The frequency and variety of these events seems to dictate the need for special attention. That is, the need to avoid altitude loss during decelerating maneuver may require more emphasis during initial training.

The fact that the aircraft underflies the planned flight path seems to be at least in part attributable to:

- 1) cockpit geometry and the physics of the helicopter deceleration;
- 2) the need to fly eyes-out to judge the deceleration rate (needed) and eyes-in to monitor power, airspeed, and altitude trends; and
- 3) the lack of a radar altimeter which provides a useful warning eyes-out; that is, a pointer on an instrument or head down warning light are not sufficient.

The steep decelerating descent into obstructions has particular application to heliports in metropolitan areas. This is true even during the visual segment of an instrument approach. Consider a decelerating dive for the landing site, after a high, fast break-out, the aircraft may hit a fence or just put the tail into the surface during the final visual deceleration.

SECTION 11

HIGH ALTITUDE OPERATIONS

OVERVIEW

This section covers situations where certain illusions may result in helicopters climbing or descending into obstructions very close to the takeoff and landing site. In addition, the issue of working into loose snow is addressed. The snow issue once again includes concern for adequate power margins.

TAKEOFF INTO AN OBSTRUCTION SCENARIO (11A)

The helicopter lifts-off from a mountain operating site (see figure 11-1). The pilot is in the right seat. The pilot attempts to climb vertically but actually moves back and to the left striking a tree with the main rotor and crashing (see figure 11-2). The pilot wanted to check power margin and engine operations before departing the site. The area was covered with a heavy haze limiting visibility to less than a mile.

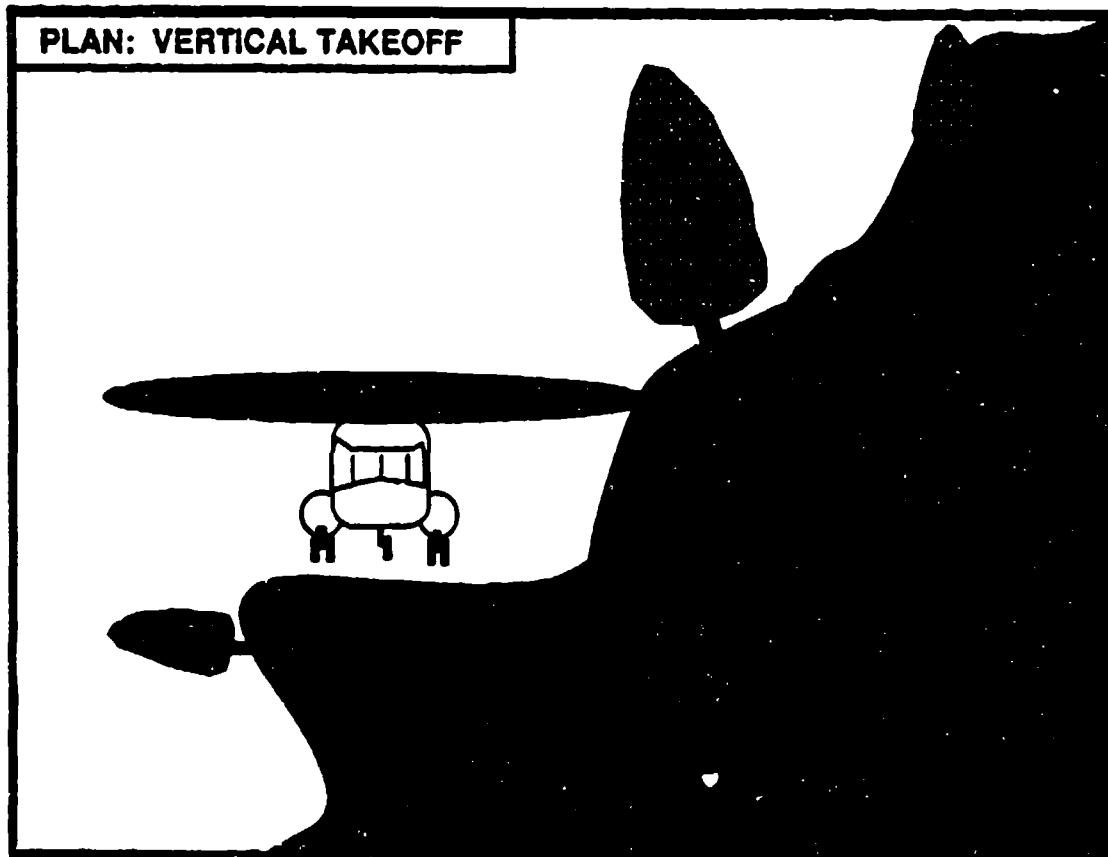


FIGURE 11-1. HIGH ALTITUDE TAKEOFF

ANALYSIS

It is almost impossible to get pilots to climb vertically from a small landing area. They will typically pick up a set of near field cues like the tree in figure 11-2 and keep the same relative picture as the aircraft ascends. This is an experience and training issue which varies from aircraft to aircraft. Primarily pilots need to pick other near field cues which will assure that the aircraft does not drift out of safe airspace as it ascends.

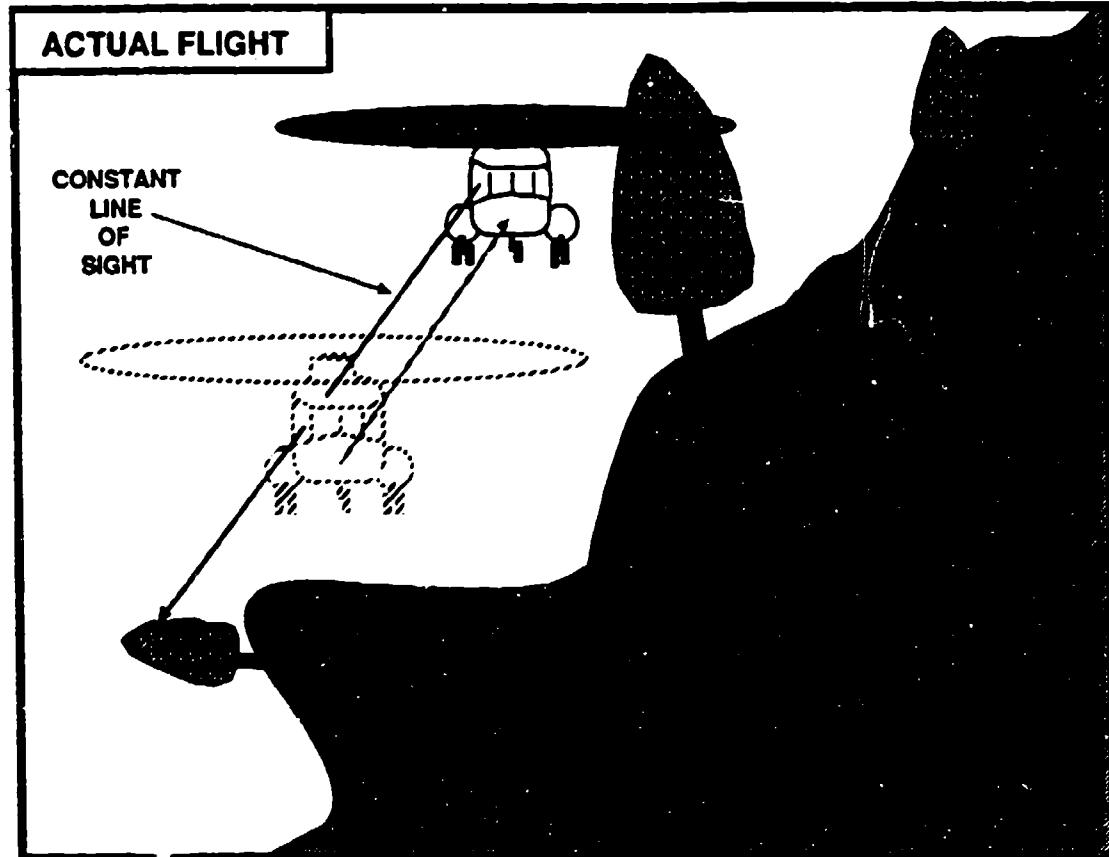


FIGURE 11-2. HIGH ALTITUDE TAKEOFF INTO OBSTRUCTION

HIGH ALTITUDE ICE OVER SNOW SCENARIO (11B)

The pilot attempted a takeoff from a hard pack operating site with a maximum load of passengers. The pilot conducted an IGE power margin check and concluded that a suitable margin of power was available. The takeoff was slightly upgrade but his path was selected because of the wind line and obstruction elsewhere. The aircraft accelerated forward but was unable to climb, eventually slowing to a low IGE hover. As the aircraft slowed, it became involved in a snow cloud, the aircraft accelerated into rearward flight. Eventually the tail touched down and the aircraft rolled over (see figure 11-3).

[In a similar situation, a lost (en route) pilot elected to terminate the flight in the face of deteriorating weather and approaching darkness. The aircraft descended into an IGE hover at a high altitude site and became involved in a snow cloud before the pilot

could complete the landing. The aircraft accelerated to the rear and crashed as above (see figure 11-4). The pilot did not have sufficient power to execute a departure.]

ANALYSIS

The problems with recirculating snow are well known. A number of accidents involved some variation of one or the other of the two above events.

The important issue is power. If a helicopter is to operate into an area where an IGE hover or landing may involve operation over loose snow, a prudent pilot must insure that sufficient power is available to execute an expeditious departure. This need, to be concerned about power margins, applies to initial takeoffs, planned landings, and the possibility of needing to conduct an emergency landing.

The exact or complete solution is beyond the scope of this effort but a suitable approach might include doubling or tripling the power margin ordinarily required for an IGE takeoff.

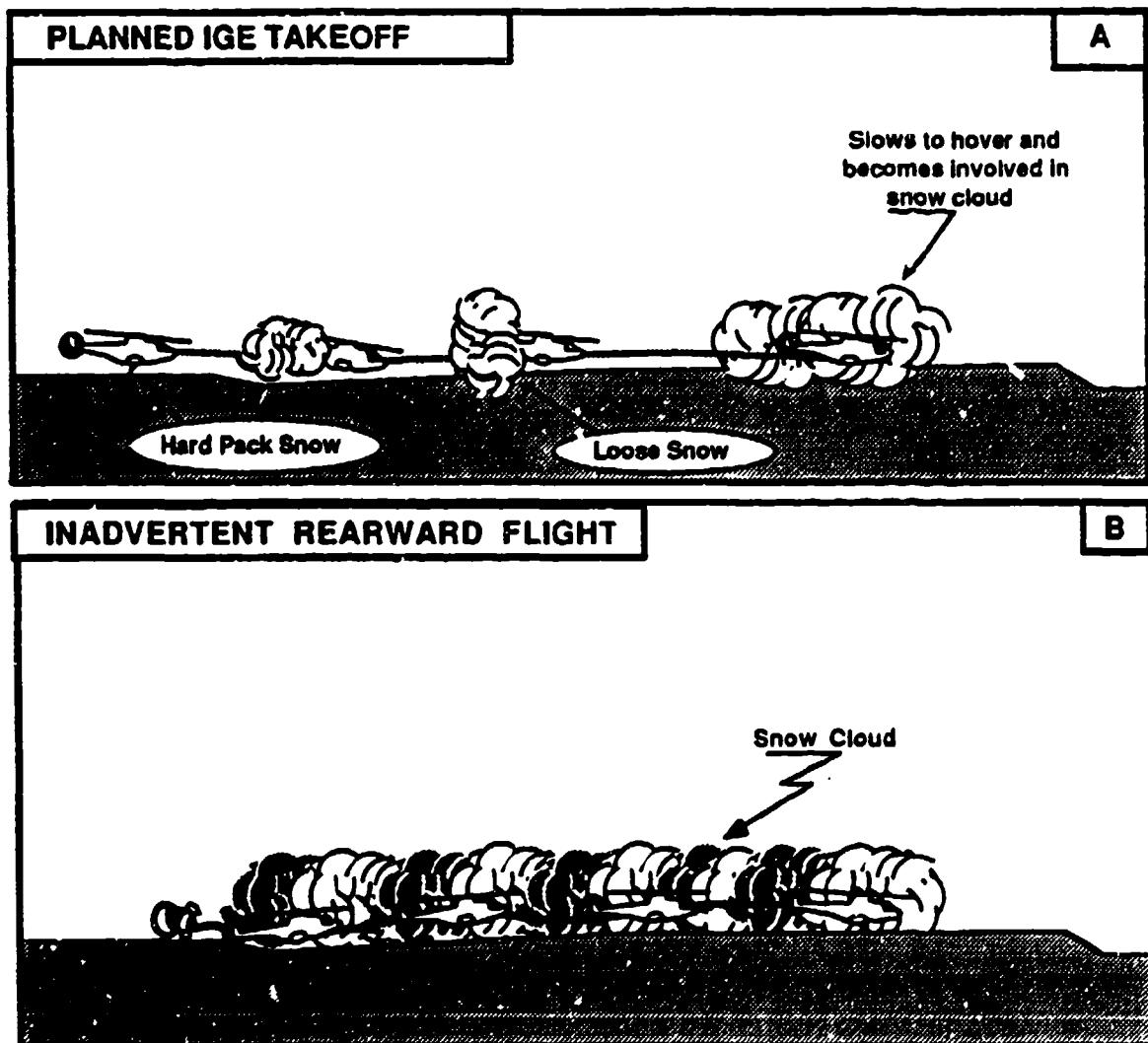


FIGURE 11-3. ATTEMPTED HIGH ALTITUDE TAKEOFF IN LOOSE SNOW

OBSERVATIONS AND FINDINGS

Pilots attempting to depart a confined takeoff area, under DVC, need to be aware of the tendency to back-up if they look at some fixed point on the ground as the aircraft climbs.

When determining the margin of power required for takeoff or landing, pilots should develop special procedures for operations which may involve difficult visual conditions (blowing snow, etc.). The margin of power available for takeoff may need to be doubled or tripled to insure that the lack of adequate power does not become a causal factor in an accident. It is possible that the IGE takeoff techniques should be precluded under such circumstances.

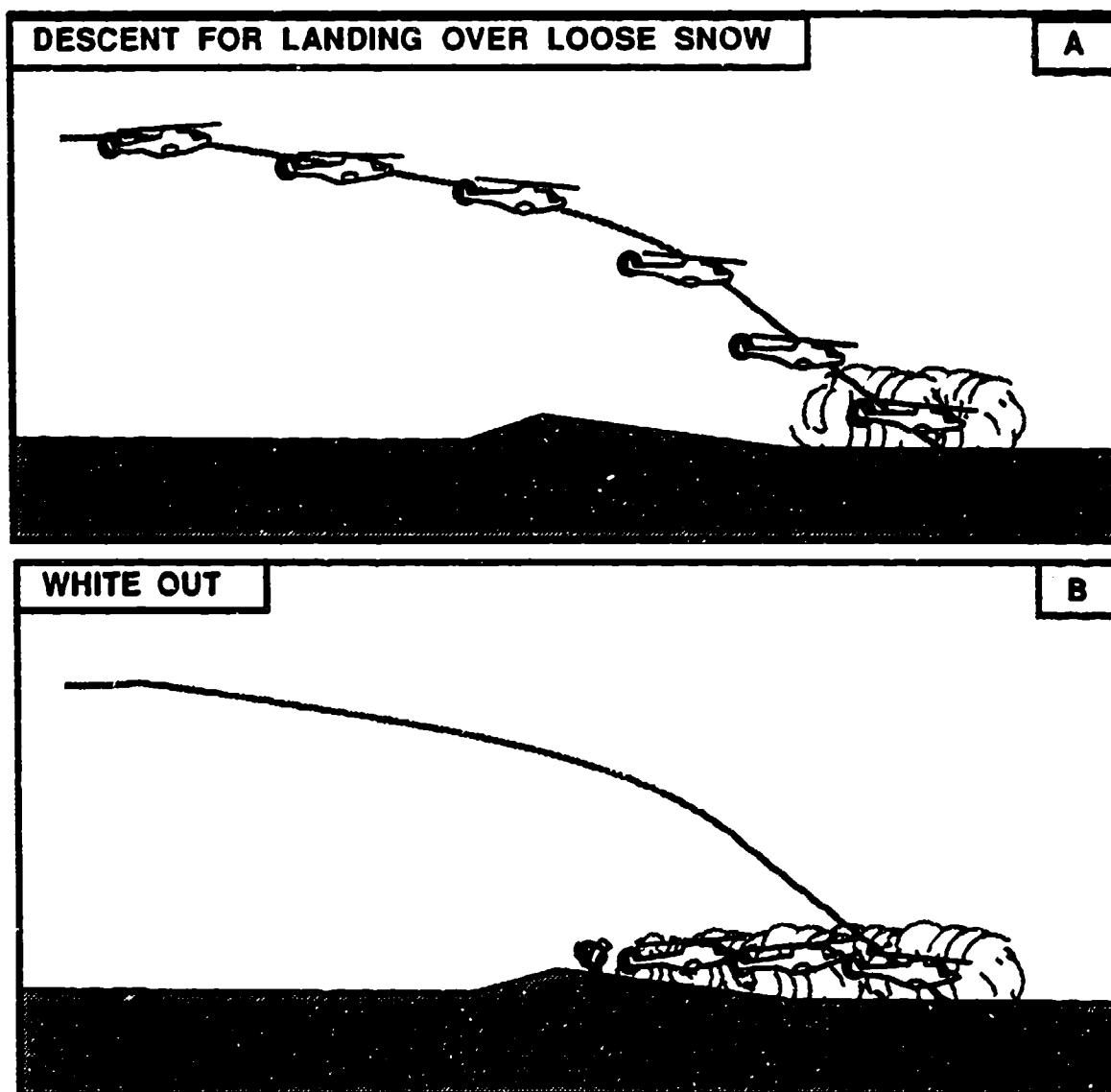


FIGURE 11-4. ATTEMPTED HIGH ALTITUDE LANDING IN LOOSE SNOW

SECTION 12

VISION ENHANCEMENT OPPORTUNITIES

INTRODUCTION

This section reviews the potential application of vision enhancement equipment to ameliorate the pilot's task under difficult visual conditions.

GENERAL DISCUSSION

Many technologies are available today for application to obstruction avoidance. This section does not strive to deal with the details of each and every one of these candidates but it does attempt to put them in perspective.

First, anyone interested in applying a new or old technology to a civil helicopter operation must understand that any opportunity for change must be approached from a total system perspective. This is not just an aircraft system, it is a civil aircraft which must make money by transporting passengers or equipment. With new technology installed, and new procedures established, the new aircraft system must meet civil criteria (not military criteria) for safety when operated in NAS.

Second, the majority of United States rotorcraft operations conducted under Part 91 and Part 135 (of the FARs) are single pilot. This establishes a significant difference between the civil and military operational experience, the later being a two pilot operation. This difference between civil and military operations puts a somewhat different perspective on many military derived display and workload solutions, suggesting a need for caution which is well known within the FAA.

Third, the civil rotorcraft operation is not limited to the application of passive systems. Active systems which radiate are not a concern in the civil environment. Cost, functional reliability, and weight are the principal concerns of the civil client. There may be concepts which represent the application old technology or less expensive applications of new technology.

Fourth, this report does not define a situation where a helicopter is required to operate in a military nap of the earth (NOE) mode. Nothing presented in this report should be so construed. From a sensor standpoint, rotorcraft flight should be conducted well above obstructions or laterally separated from obstructions while en route. Sensors may be applied to the task of:

1. detecting prominent natural or man-made terrain details to confirm separation, and/or
2. confirming location of the aircraft as it proceeds en route using other navigation means for routing, and/or

3. presenting the pilot with an enhanced outside view under DVC, view which contributes to the pilots ability to fly the aircraft either from a situational awareness standpoint or a closed-loop flight path control standpoint.

Fifth, the need to detect and avoid wires and other such obstructions, on a routine basis, is probably limited to para-military and EMS helicopter operations required to operate into remote sites to conduct security and life saving operations. The part of this operation which is conducted in the high risk, obstruction rich environment is brief and can be accomplished within a constrained parametric envelope which is dramatically more predictable and docile than the typical flight envelope of military aircraft involved in land warfare.

HELMET MOUNTED DISPLAYS

I² Systems. The third-generation image-intensifier (I²) tubes are currently employed in the AN/AVS-6 mounted on the helmets of military pilots. This system has a limited field-of-view (about 40 degree) and depends upon the availability of light, but it looks where the pilot looks. The pilot can look under the eye pieces to scan cockpit instruments and look through the devices to scan outside. Details of current military equipment are included in references 37 and 38.

The AN/AVS-6 equipment requires the pilot to look into the night vision goggle (NVG) device. Improved helmet mounted I² devices allow pilots to look through a transparent I² display (attached to the helmet). In many cases, two displays will be provided, one for each eye. The transparent nature of this display precludes the need to look under or around the NVGs.

The Army and U.S. Marine Corps are in the process of procuring heads up display (HUD) equipment which can be attached to the current AN/AVS-6 devices. This HUD device allows flight display data to be superimposed on the NVG image. This combination appears to hold a great deal of promise for civil applications as well. (Two NVG - HUD arrangements were investigated as a part of this effort (see reference 39)).

FLIR Systems. There are numerous thermal imaging sensor systems which can provide data to helmet mounted displays. Thermal imaging systems detect heat radiated by objects and do not need light to function. These devices can provide the pilots with an image of the infrared scene. At certain times of day, and under certain environmental conditions, the FLIR image may not meet the needs of some applications. The capability of FLIR systems varies substantially from system to system, as does the cost.

The FLIR image can be presented on a monocular display positioned over one eye leaving one eye unaided. Alternately, the same image can be presented on a visor display to both eyes at the same time. In both of the above cases, the pilot's head movement must be accurately tracked so as to allow the FLIR sensor to be pointed in the direction the pilot is looking. The sensor is always mounted some distance from

the pilot's head and this produces a certain amount of parallax. This is more of a problem when the pilot is able to see many features (in his field-of-view) unaided. The unaided image and the FLIR image will not match up because of the parallax or any other misalignment of the FLIR sensor. (Two helmet mounted display, FLIR systems, were evaluated in support of this effort).

MILLIMETER WAVE (MMW) RADAR

The U.S. Army has an ongoing program to develop an obstacle avoidance system (OASYS). This program may produce a MMW radar capable of providing obstruction avoidance guidance and images for presentation to pilots similar to the I² and FLIR display formats. The civil community will probably not require the same OASYS equipment because the civil operator is expected to use procedures to stay clear of the obstruction rich military environment which establishes the need for an OASYS. Nevertheless, the OASYS program may produce a system which can be used to locate and identify obstructions as part of a positive flight path management system for large civil rotorcraft to use during operations into and departing metro areas.

IMAGE FUSION

Images from I², television, and FLIR can be fused to produce an enhanced image. This approach maximizes the information content available on a single display. This is a capability which is available today and holds the promise of allowing TV-FLIR images to be fused for day operations and a I²-TV-FLIR images to be fused and presented during night operations.

COCKPIT DISPLAYS

Displays can be mounted above the instrument panel or in the instrument panel. In both cases, TV, MMW radar, FLIR and I² sensors can be used to generate images for the displays. Flight data can be written over these images if this is determined to be a desired format.

When compared to helmet mounted vision devices, it is generally correct to expect more detail and clarity from a panel mounted display.

SENSOR MOUNTING

Vision augmenting sensors can be mounted on gimbals and articulated or fixed. There are arguments for both arrangements. The gimbal system can be used to stabilize the image (remove vibration) or point the sensor at a selected location. It is also possible to automatically track a light, hot spot, or cold spot with the sensor. Alternately the pilot can slew the sensor to look at a given point in space.

EXTENDED VISUAL RANGE

While both I² devices and FLIR devices have limits, they both have the potential of extending the visual range of a pilot. This is especially true when the target is cooperative or when the target is illuminated by a light or infrared (IR) source on the aircraft.

ENHANCED SIGNATURES

It is possible to stall radar reflectors, lights, and IR sources on heliports and otherwise enhance the signatures of obstructions and landing surfaces. Such an enhancement will allow the target area to be seen through environmental conditions which would otherwise preclude effective sensor operation. This type of enhancement could have the effect of extending the visual range of the pilot at the completion of an instrument approach. Such marking and illumination enhancement techniques might also be used to establish a lead-in marking (light) system (to a heliport or airport) that is similar in many ways to runway lead-in lighting.

HELICOPTER EXTERNAL LIGHTS

There are many opportunities to provide helicopter organic illumination for I² devices. This light can range from high powered, long range spotlights to low intensity floodlights. I² sensors are very good at detecting wires when the illumination source light makes a small angle with the reflected light (from the wire or wire support). There has been very little work in this area because the military has conducted most of the work and they have been more interested in covert applications of vision technology.

OBSERVATIONS AND FINDINGS

There is a need for improved vision and obstruction detection sensor and displays as established elsewhere in this report. Although there are a variety of off-the-shelf equipments which can be used to enhance the ability of civil helicopter pilots to see and avoid obstructions, very few have been specifically designed for the civil application. They are for the most part designed for modes of flight which are inappropriate for civil rotorcraft operations. The civil environment must be understood and a sensor-display arrangement must be designed to meet the specific needs of the civil rotorcraft operations before the value of such systems can be evaluated from a cost-benefit basis.

SECTION 13

SUMMARY OF OBSERVATIONS AND FINDINGS

INTRODUCTION

The following summarizes the important findings developed as a result of this analysis. These findings and related suggestions are offered here as points of departure, and do not represent proposed final solutions.

SIGNIFICANCE OF OBSTRUCTION AVOIDANCE

If rotorcraft are to continue to populate the lower airspace in a productive capacity, there will be an ever present priority need for the systematic application of obstruction avoidance technology and crew managed obstruction avoidance techniques during all low altitude operations from takeoff to landing. This includes both VMC operations and IFR operations with and without visual components. A broad application of obstruction avoidance concepts is required because of the overriding need to enhance the operational capability of rotorcraft and other powered-lift aircraft in ways which minimize the necessity for protected airspace in all near-terrain applications. Thus, obstruction avoidance is one of the most important constructs of the rotorcraft and powered-lift segment of the transportation system.

SCOPE OF APPLICABILITY

There are many affordable and practical opportunities to improve training, procedures, techniques and system-equipment characteristics to enhance the safety of operations during takeoffs and low altitude en route flight, as well as during descents to landings in remote areas. Conversely, there is no need for equipment to conduct military type terrain following/terrain avoidance flight operations at low altitudes.

ESTIMATING VISUAL RANGE

It is difficult to judge visual range. This is especially true when the pilot is inexperienced and when operations are conducted at night. The following apply to the visual range issue and were developed as the result of data review and analysis.

1. Pilots can learn to use height and look down angle (over the nose) to estimate their ability to see during day operations.
2. Pilots can improve the safety of their operations by learning how to operate at speeds which are consistent with their ability to see.
3. When a prudent pilot is forced by lowering ceilings or visibility to fly below 200 feet AGL in the daytime and 300 feet AGL at night, continued flight constitutes emergency operations. Under such conditions a prudent pilot will minimize forward speed to avoid obstructions until a safe landing can be accomplished.

4. There is no flight manual or advisory circular which discusses the need to control speed in the ways addressed above.
5. While not totally applicable, many of the requirements established in AC No. 135-14, "Emergency Medical Services/Helicopter (EMS/H)," appear to provide useful guidelines for many point-to-point operations under DVC.

NEED FOR EXTERNAL LIGHTS, ELECTRONIC SENSORS AND DISPLAYS

Many helicopter pilots risk flying down into the obstruction rich environment in an effort to see the area illuminated by their landing light or spotlight so as to follow a road or terrain feature or to conduct a site reconnaissance before landing. The following are related findings:

1. A single (basic equipment) landing light does not have sufficient range to allow route following or site reconnaissance while remaining at a prudent minimum en route altitude of above 300 feet AGL.
2. It is appropriate to equip aircraft involved in routine operations to and from remote sites (such as EMS operations) with high intensity searchlights to conduct reconnaissance and numerous floodlights to illuminate the landing area on final.
3. The issue of backscatter and impairment of pilot's night vision is a serious consideration when employing powerful white lights during helicopter operations.
4. Forward illuminating lights can probably enhance the operations of certain night vision systems.
5. There is no known reason for civil rotorcraft to fly point-to-point in an obstruction environment which requires a sensor-display system to detect unexpected obstructions.
6. Sensors can be used to enhance obstruction avoidance in two ways: (a) to help detect obstructions during a pre-approach reconnaissance so that the crew can select the best flight path for an approach and departure, and (b) to detect known obstructions (as landmarks) and confirm that the aircraft is being flown along the planned flight profile and will remain clear of all obstructions.
7. Both head down and head-up, eyes-out displays are applicable to obstruction avoidance tasking. Simple head mounted systems may meet some needs while others will require more elaborate fused data concepts.
8. In some cases, the signatures of landmarks, obstructions, and landing areas will need to be enhanced to facilitate detection and identification via advanced sensors. In still other cases the aircraft will be able to radiate or illuminate areas of interest to facilitate sensor operation.

ESTIMATING HEIGHT AGL

There were numerous cases where aircraft were flown into terrain during descending forward flight. The following were observed to be contributing factors:

1. Many aircraft operated under DVC were either not equipped with a radar altimeter, or it did not provide a suitable warning, or the pilot misused/miss-adjusted the device.
2. All aircraft operating over water or snow have a priority need for a radar altimeter.

COCKPIT OBSTRUCTIONS TO VISION

Pilots are not universally aware that:

1. The nose up attitude associated with decelerations will sometimes cause them to lose visual contact over-the-nose.
2. Loss of over-the-nose ground reference will cause pilots to inadvertently fly below their intended flight path and into obstructions on short final.
3. Cockpit geometry-vision characteristics cause pilots to climb backward into obstructions during attempts to execute vertical takeoffs.
4. Cockpit geometry-vision characteristics induce inadvertent descents during low altitude turns.

FLYING QUALITIES

Helicopter flying qualities change, sometimes dramatically, when helicopters are slowed and operated at speeds below about 50 knots.

1. Pilots are not sufficiently aware of, nor are they sufficiently respectful of the poor flying qualities of their helicopters with respect to slow speed operations under night and day DVCs.
2. Pilots do not appreciate the importance of a reliable airspeed indication until faced with rapidly degrading visual conditions and an inadvertent deceleration to very slow speeds.
3. The attitude and trajectory characteristics which can be expected during slow speed operations, where the pilot is essentially non-responsive (which often happens during inadvertent IFR events) have never been systematically recorded and analyzed. The lack of published data depicting these trajectories perpetuates a situation where most pilots do not appreciate the dire consequences of slow speed flight under DVC. As a result, they are not on guard to avoid inadvertent slow speed flight.

POWER CHARACTERISTICS

Helicopter power characteristics were involved in many accidents where the aircraft struck the terrain, wires, or other obstructions. The variety of these accidents indicates that there is a general lack of understanding of helicopter performance characteristics. The following were observed during the analysis of the accidents

considered in this study:

1. Power margin required for takeoff, hover, acceleration to a climbing departure, or landing during crosswind operations is substantially higher than the that required for similar operations into winds of the same magnitude (with no crosswind component).
2. Pilots do not universally appreciate the need to monitor the margin of power available for climbing flight when operating near obstruction hazards.
3. Pilots do not universally understand the agility limitations of their aircraft during forward flight near terrain.
4. Pilots operating under DVC sometimes decelerate unknowingly onto the back side of the power required curve.
5. Many pilots do not have a satisfactory technical understanding of slow speed helicopter performance.

VFR-DVC ROUTES

Helicopters tend to operate within a local area during the majority of their flights. Today's navigation and communication technology will allow the most often utilized routes to be documented much the way they are on "helicopter route charts." The following might apply to such an operation and are illustrative of the improvements which, if established, could result in a more orderly operation at the lower altitudes:

1. Local operator routes might be formalized, route checked for obstructions, and documented by individual operators. These routes would enable local operations under difficult visual conditions.
2. Some local routes are short, well known, and frequently traveled. These routes might be defined by operators along with the minimum altitudes and maximum airspeed allowed. Other less frequently used routes might require higher (AGL) en route altitudes.
3. Such operations might be further enhanced by the inclusion of I² or FLIR imaging systems, or radar-beacon arrangements. These systems would be used to detect other visual traffic and follow roads (etc.) used to establish routes and waypoints.
4. Some local routes or waypoints might lead directly to a special VFR approach (lead-in) route possibly enhanced by markers, lights, or IR signature enhancements.

NEED TO DEFINE OPERATIONAL CONCEPTS

Subsequent studies of obstruction avoidance issues will require a characterization of future rotorcraft flight operations to insure that all solutions are developed with common objectives in mind. The Appendix to this report, "Rotorcraft Obstruction Avoidance", is offered as a point of departure. This notional system description (for research and development only) will provide an operational context for trade-off studies and facilitate the development of FAA approved and promulgated changes to the National Airspace System (NAS) in the long term.

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LIST OF ACRONYMS

AC	=	Advisory Circular
ADM	=	Aeronautical Decisionmaking
AFCS	=	Automatic Flight Control Systems
AGL	=	Above Ground Level
CTR	=	Civil Tiltrotor
CTW	=	Civil Tiltwing
DH	=	Decision Height
DVC	=	Difficult Visual Condition
EMS	=	Emergency Medical Services
EMS/H	=	Emergency Medical Services/Helicopter
EVA	=	Electronic Vision Aids
FAA	=	Federal Aviation Administration
FAR	=	Federal Aviation Regulation
FLIR	=	Forward Looking Infrared
GPS	=	Global Positioning System
GS	=	Ground Speed
HV	=	Height-velocity
IFR	=	Instrument Flight Rules
IGE	=	In Ground Effect
IMC	=	Instrument Meteorological Conditions
IR	=	Infrared
I ²	=	Image (light) Intensification
LOS	=	Line of Sight
MMW	=	Millimeter Wave (Radar)
NAS	=	National Airspace System
NM	=	Nautical Miles
NOE	=	Nap of the Earth
NTSB	=	National Transportation Safety Board
NVA	=	Night Vision Aiding
NVG	=	Night Vision Goggle
OASYS	=	Obstacle Avoidance System
OGE	=	Out of Ground Effect
TV	=	Television
VFR	=	Visual Flight Rules
VMC	=	Visual Meteorological Conditions

**SUGGESTED CONCEPTS OF OPERATIONS
FOR THE EVALUATION OF
ROTORCRAFT OPERATING AT LOW ALTITUDES**

INTRODUCTION

The first obstruction avoidance study explored a wide variety of faulty operational concepts and procedures which contributed to accidents. From time-to-time, improvements have been incorporated by the industry and others have been suggested. Some of these improvements have been mentioned in earlier sections, many have not. Still other improvements are being considered as this report is being completed. In recognition of the importance of this evolutionary process, this section presents a collection of improved operational procedures and concepts, organized under a synthesized route structure (which was developed for this document) to help future analysts understand how pervasive the need for obstruction avoidance technology is to the eventual expansion of the rotorcraft transportation segment. Thus, this section provides an incomplete and unofficial characterization of rotorcraft operations in the year 200X. It is simply a first step in the process of building a common and accurate database to support future research and development efforts.

NEED TO DEFINE OPERATIONAL CONCEPTS

Subsequent studies of obstruction avoidance issues will require a much more elaborate characterization of future flight operations to insure that all solutions are developed with a common objective system in mind. This objective system description should be revised from time-to-time and revisions would be provided to all interested parties. A characterization such as this is required by engineers and scientists new to the subject but interested in applying mature and new technology to existing and anticipated needs of the industry. In this regard, this characterization should provide an operational context for trade-off studies, and it should establish a point of departure for the formal development of an official industry or government estimate.

SIGNIFICANCE OF OBSTRUCTION AVOIDANCE

It appears that obstruction avoidance is one of the most important constructs of the rotorcraft and powered-lift segment of the transportation system. That is, if rotorcraft are to continue to populate the lower airspace in a productive capacity, there will be an omnipresent priority need for the application of obstruction avoidance technology and techniques during all low altitude operations from takeoff to landing. This systematic consideration of obstruction avoidance includes both visual operations and IFR operations with and without visual components. This situation exists because of the overriding need to enhance the operational capability of rotorcraft and other powered-lift aircraft to minimize the need for protected airspace in all near-terrain applications of these configurations.

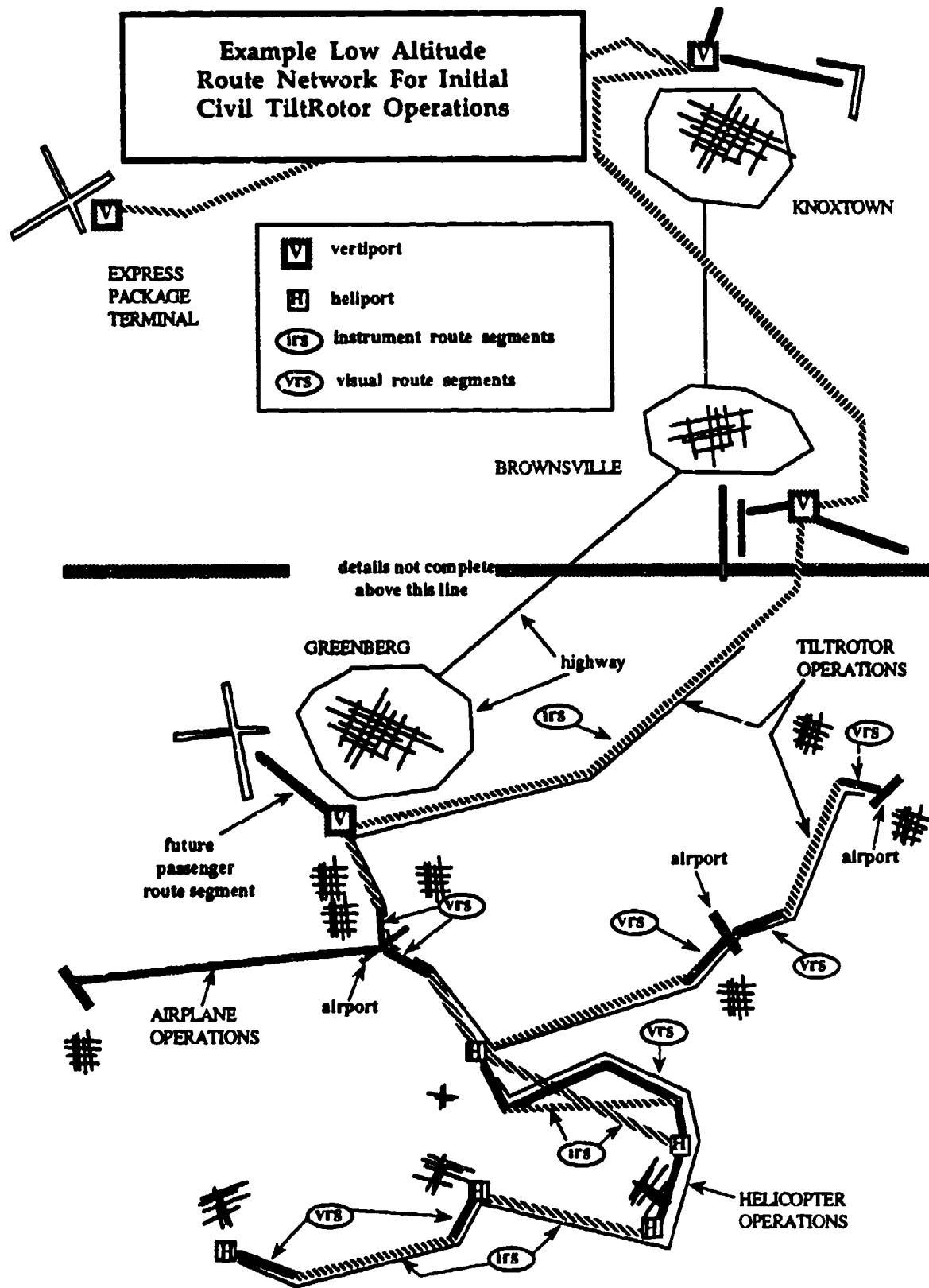


FIGURE 1. LOW ALTITUDE AIRWAYS FOR ROTORCRAFT

PREMISE OF AIRWAYS DESIGN

The details developed in this section respond to the premise that the government will seek to expand the application of the rotorcraft to enhance the entire air and ground transportation system. In particular, the section anticipates that there will be a need to expand the application of rotorcraft for: (1) local community needs (EMS and priority package delivery, as two examples), (2) offshore energy exploration, and (3) as part of a feeder system for large, high speed rotorcraft such as the European Helicopters EH-101, a civil tiltrotor (CTR), or a civil tiltwing (CTW). While some powered-lift aircraft will not stay in the low airspace as long as helicopters, they will intermingle at a multitude of terminal-exchange points. For this reason, they are included in the following overview as a logical member of the rotorcraft segment of the total air and land transportation system.

EXAMPLE ROUTE NETWORK

Figure 1 illustrates the principal features of a conceptual regional low-airspace airways system which might be viable by the early twenty-first century. This approach was synthesized as a result of reviewing references 1 through 5 and, if implemented would employ concepts embodied in reference 6, the "Baltimore-Washington Helicopter Route Chart." This route network and the operational concepts which support it should accommodate airplane, rotorcraft, and powered-lift aircraft, as well as facilitate the introduction of the CTR and expand the availability of air services to regional airports. The short length of some route segments dictates the use of visual techniques whenever the weather allows. This may include IFR operations under DVC much the way very high altitude flights are conducted, visually but under the management of the IFR system. In terms of obstruction avoidance, this route structure and the related operational procedures should adequately support initial analytical and development efforts.

EN ROUTE PROCEDURES

Figures 2 and 3 illustrate the low altitude en route problem. Figure 2 emphasizes the contact navigation aspect of DVC operations while figure 3 provides a more detailed analysis of the altitude consideration. This figure indicates that for the planned minimum pressure altitude, the radar altimeter should never fall below 500 feet (to maintain a 300 foot clearance over the highest obstruction along the route if the pilot is inattentive and inadvertently descends below the planned minimum en route altitude). The pilot should observe a 700 foot minimum radar altitude en route to insure a 500 foot clearance over obstructions. Minimums are established by the terrain being overflowed.

Each leg of the flight will have a minimum pressure altitude which the pilot maintains en route. This pressure altitude will, at a minimum, correspond to a pressure altitude which will provide the 700 radar altitude terrain clearance. The radar altimeter should be set to alert the pilot to inadvertent descents to avoid flying into the airspace just above the highest obstruction. A radar altitude alert of 500 feet should keep the aircraft several hundred feet above obstructions under the worst possible situation. A warning light and aural alert will warn the crew of a low altitude situation.

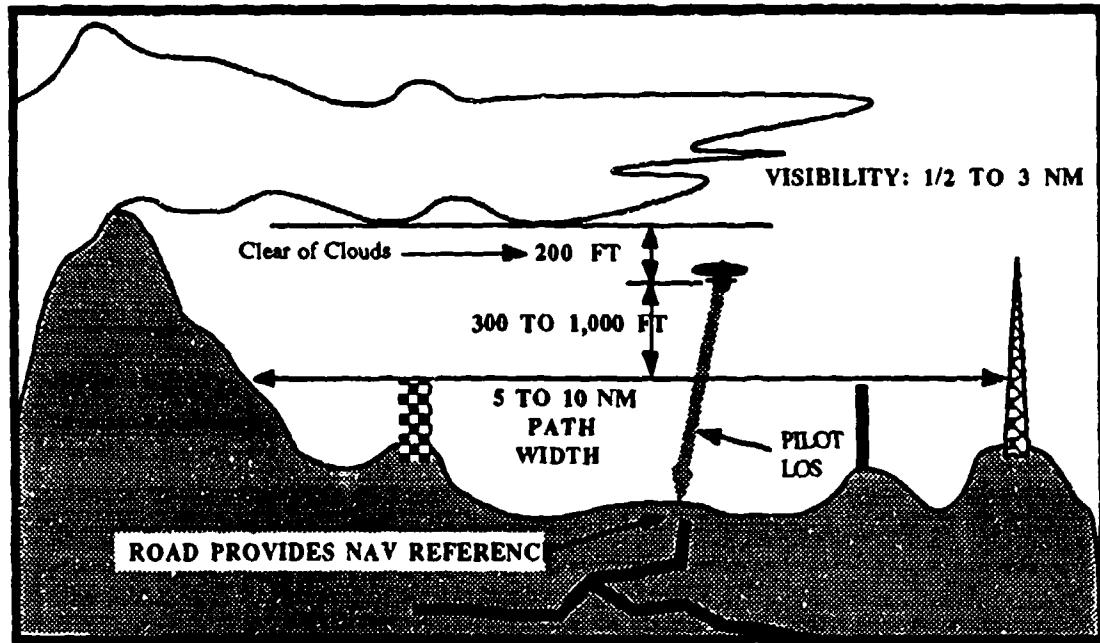


FIGURE 2. PLANNING EN ROUTE DVC FLIGHT
(Adapted from reference 7)

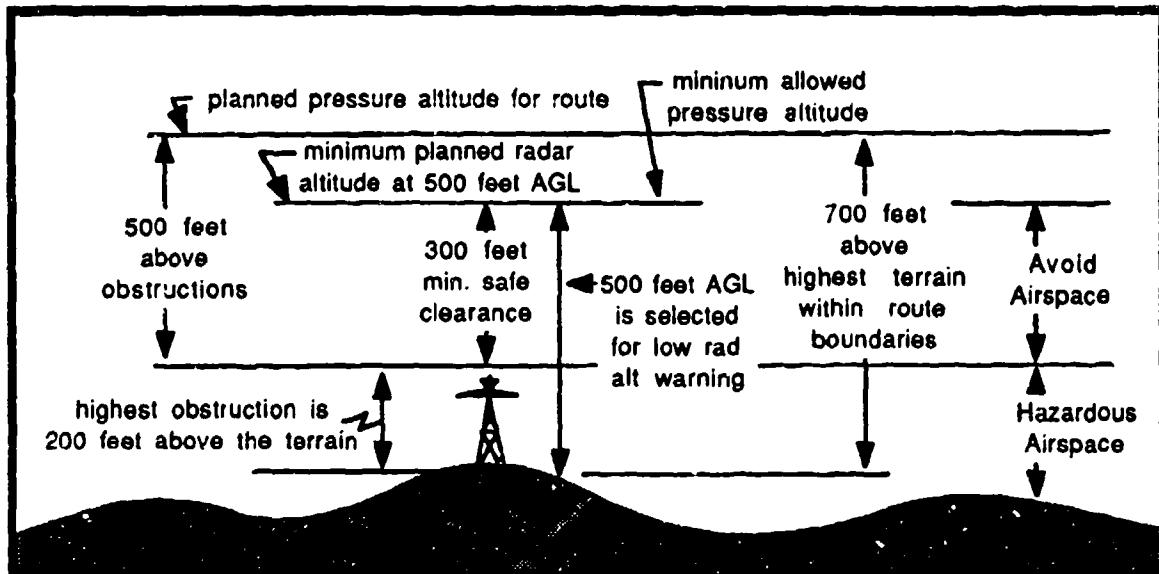


FIGURE 3. ESTABLISHING A PRESSURE ALTITUDE AND RADAR WARNING ALTITUDE FOR EN ROUTE OPERATIONS (Adapted from reference 8)

FLIGHT PROFILE ALTERNATIVES

Many of the alternatives for operations between airports and between heliports are summarized in figure 4. The following explores how one of these operations might evolve.

Departing "A" VFR-DVC, the aircraft proceeds to "B," observing the criteria illustrated in figure 3. At "B", the pilot discovers that the weather has decreased below forecast. This pilot detected and avoided inadvertent IFR because he was warned by on board sensor that the forward visibility had dropped to 2 nm.

If the pilot had not detected the descending overcast and inadvertently become involved, "E," the procedure would involve a 90 to 270 degree ("F") heading reversal maneuver and retreat to "B." Arriving at point "B," the pilot will either hold "C" and await a modified clearance, or return to the point of departure "A" if this provision is contained in the original clearance.

While holding, the pilot obtains clearance to proceed IFR (or this may have been a pre-planned event) and climbs departing "B" for "H" and beyond.

Once IFR, the pilot may execute a point in space helicopter approach "G-J" and follow a local VFR-DVC approach route "J-I" to the destination. If the weather will not support a VFR-DVC approach route to "I," the pilot will execute an instrument approach "H-I."

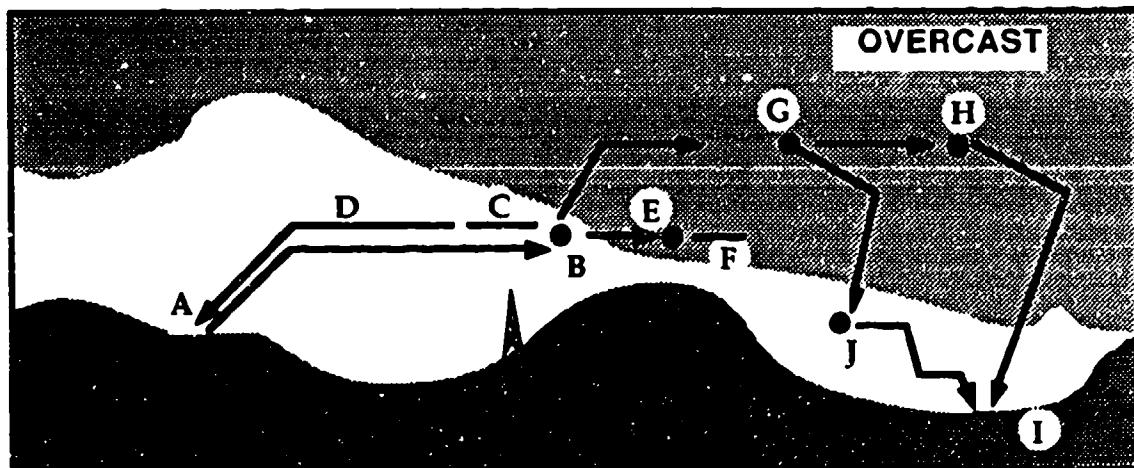


FIGURE 4. HELICOPTER FLIGHT PROFILE ALTERNATIVES

ARRIVAL AT A REMOTE SITE (NIGHT PROCEDURES)

Some operations will be conducted to remote sites. The en route phase will be VFR-DVC or IFR with a point-in-space approach to VFR-DVC en route/arrival segment. Under normal night operations, a helicopter pilot is expected to arrive at a remote landing site and descend to a safe landing using natural light, lights on the ground, and lights on the aircraft.

Nevertheless, night vision aiding (NVA) may be of significant benefit during the arrival, pre-descent phase. Arriving in the vicinity of a remote landing site, the first task is to find the site. This may mean looking for a lighted heliport or for a police car on a dark highway. Regardless, the pilot must descend to some safe (obstruction clear) altitude and verify the identity of the site and the appropriateness of the site as a potential landing site.

This process should include a high and low reconnaissance to detect obstructions, plan the approach path, and to plan the departure. Trainable search lights, landing lights, and fixed landing lights are normally used in this task. The high reconnaissance phase could involve the coordinated use of NVAs and white lights. Conventional white lights, installed on the aircraft should be adequate for the final approach to a hover.

In figure 5, an EMS helicopter has arrived in the area, conducted a search and has located an accident site involving two cars, (LOS "1" in figure 5). Having located the site, the aircraft is flown down to a lower altitude (LOS"2" in figure 5 and figure 6) to continue a pre-approach, high reconnaissance. White lights are turned on before descending. It is important for the pilot to make the transition from the dark night environment (with no lights) to the "white lights on" environment, before leaving the obstruction protected altitude established during the pre-flight planning phase and observed en route. This is true regardless of whether the pilot uses NVA or not. If it is a very hazy night, turning a white light on may produce a lot of backscatter. This may eliminate horizon cues and make the operation a bit less comfortable.

Spotlights are used to look for objects on the ground while the pilot circles above. The pilot can look at the spot on the ground through night vision goggles (NVGs) and often see more than without the NVGs. The pilot also has the alternative of looking under the NVGs and viewing the lighted area unaided. The resultant visual experiences will be different, but complimentary.

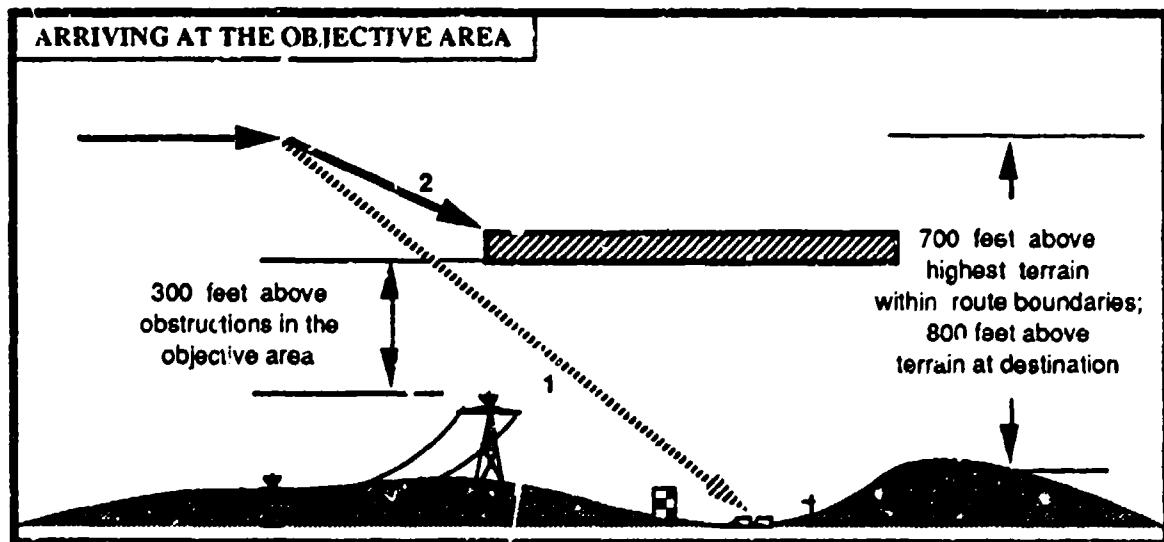


FIGURE 5. ARRIVING AT THE OBJECTIVE AREA
(Adapted from reference 8)

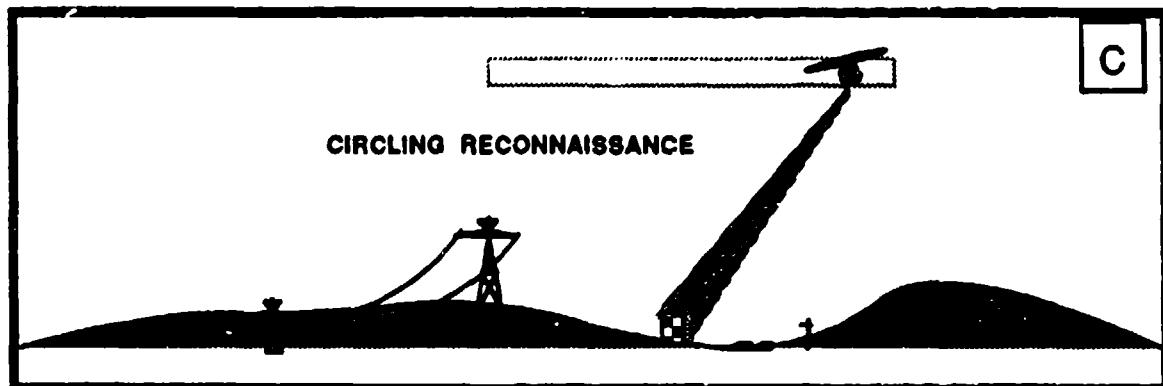
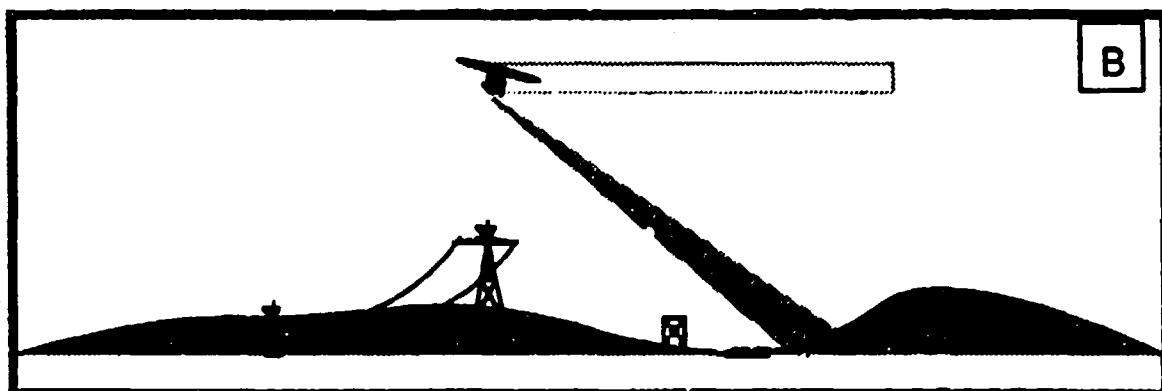
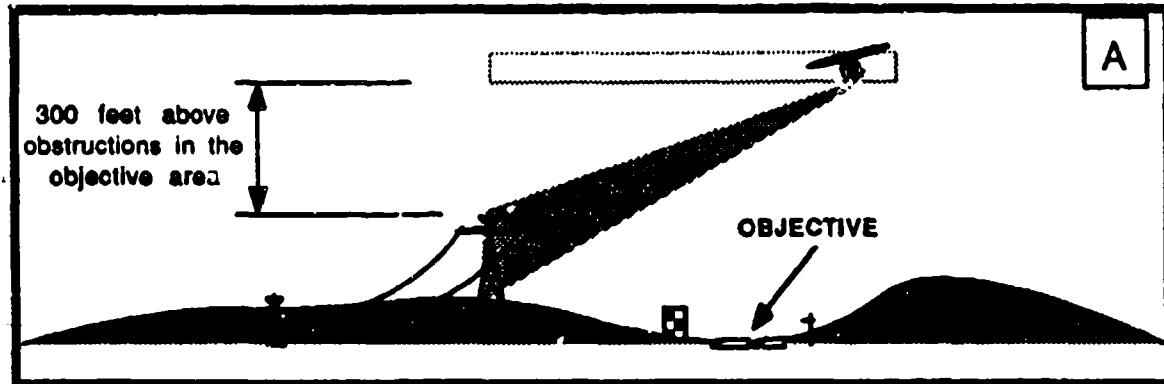


FIGURE 6. CONDUCTING A RECONNAISSANCE OF AN OBJECTIVE AREA
(Adapted from reference 8)

The pilot's head (with goggles) can be pointed at a number of different subjects (of potential interest) on the ground much faster and more accurately than the spotlight. (The ability to focus the light to get a small or large spot, the candle power of the spot, and the quickness of the motor driven articulation system of the light or lights obviously varies from system to system, as does the pilot workload associated with its application.)

Some terrain features and man-made objects may be easy to detect and interpret with the unaided eye. Other objects will be invisible to the unaided eye, yet easily detected and evaluated with NVGs. Each alternative viewing method has its attributes and its limitations. (The preceding was adapted from reference 7).

INSTRUMENT APPROACH TO REGIONAL AIRPORT

One key to exploiting existing rotorcraft in the NAS involves approaches to regional airports. This may be facilitated by making approaches to an offset (set back) threshold to allow rotorcraft (including todays helicopters) to operate to lower minima. Such an approach is illustrated in figure 7. The use of low V_{min} approach speeds, precision navigation, vision aiding systems, and reduced allowable deviation (from localizer and glide slope) procedures should allow helicopters to operate from airports which have been closed to airplane traffic (because of weather).

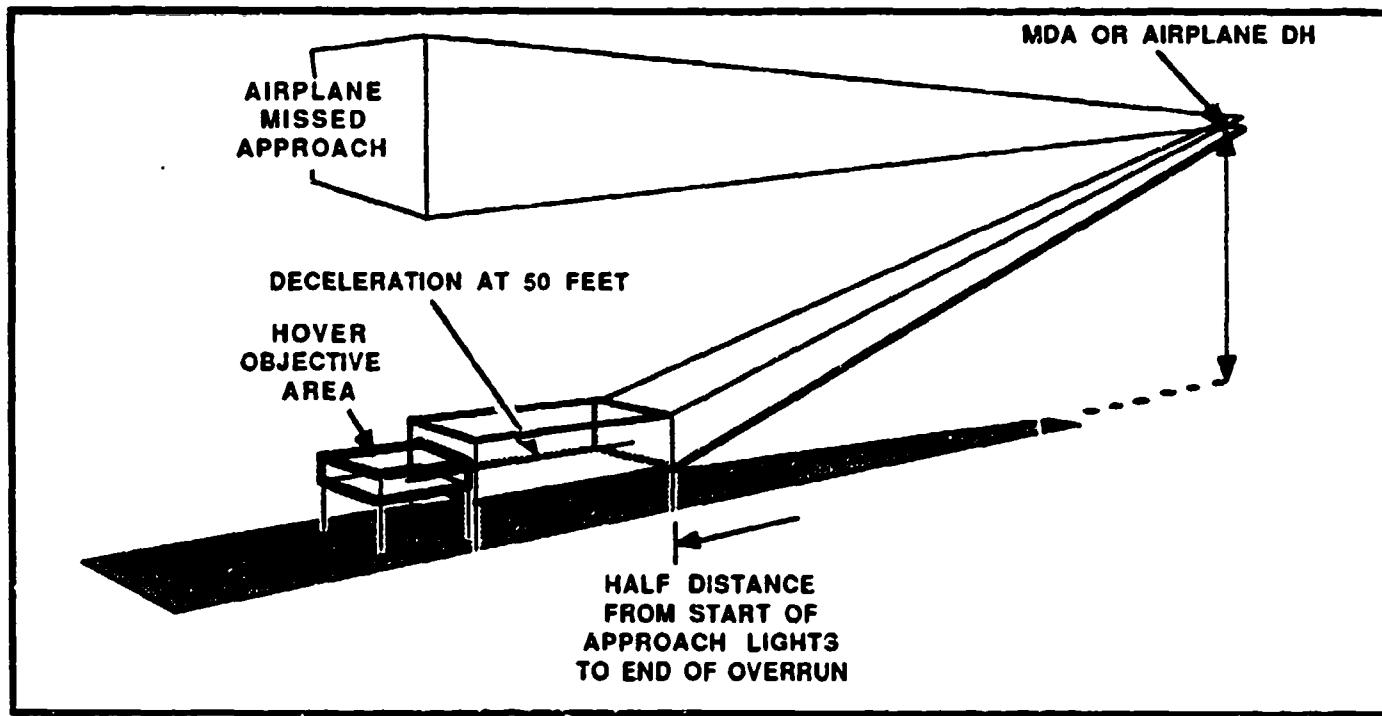


FIGURE 7. APPROACH TO A REGIONAL AIRPORT
(Adapted from reference 4)

POINT-IN-SPACE APPROACH

Point-in-space approaches have one problem today; they are often not connected. Figure 8 illustrates one concept which allows an aircraft to make an approach to a visual waypoint (an interstate highway intersection) or a special visual array which can be seen by a pilot using either aided or unaided means. The arrival array in figure 8 is connected to a VFR-DVC lead-in route. This route might be an interstate highway or a series of lights or a series of markers as shown in figure 9. This approach concept was first presented in reference 4 which explored ways to enhance rotorcraft operations through helicopter unique techniques and equipment.

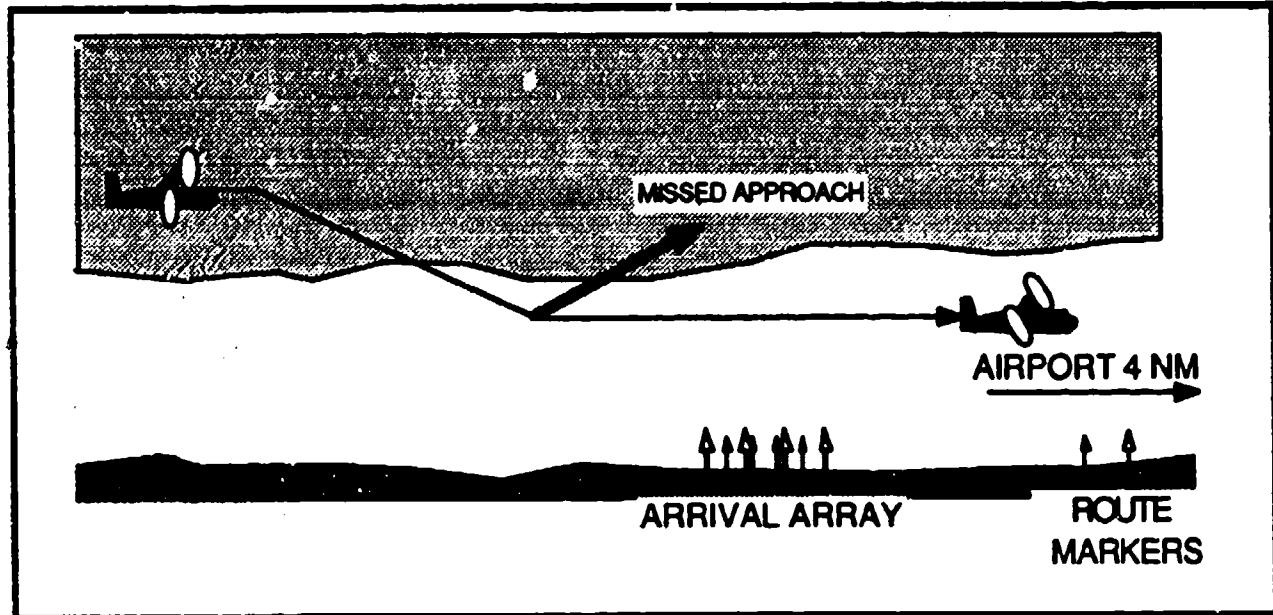


FIGURE 8. POINT-IN-SPACE APPROACH TO A VISUAL AIRWAY LEADING TO AN AIRPORT, HELIPORT OR VERTIPORT

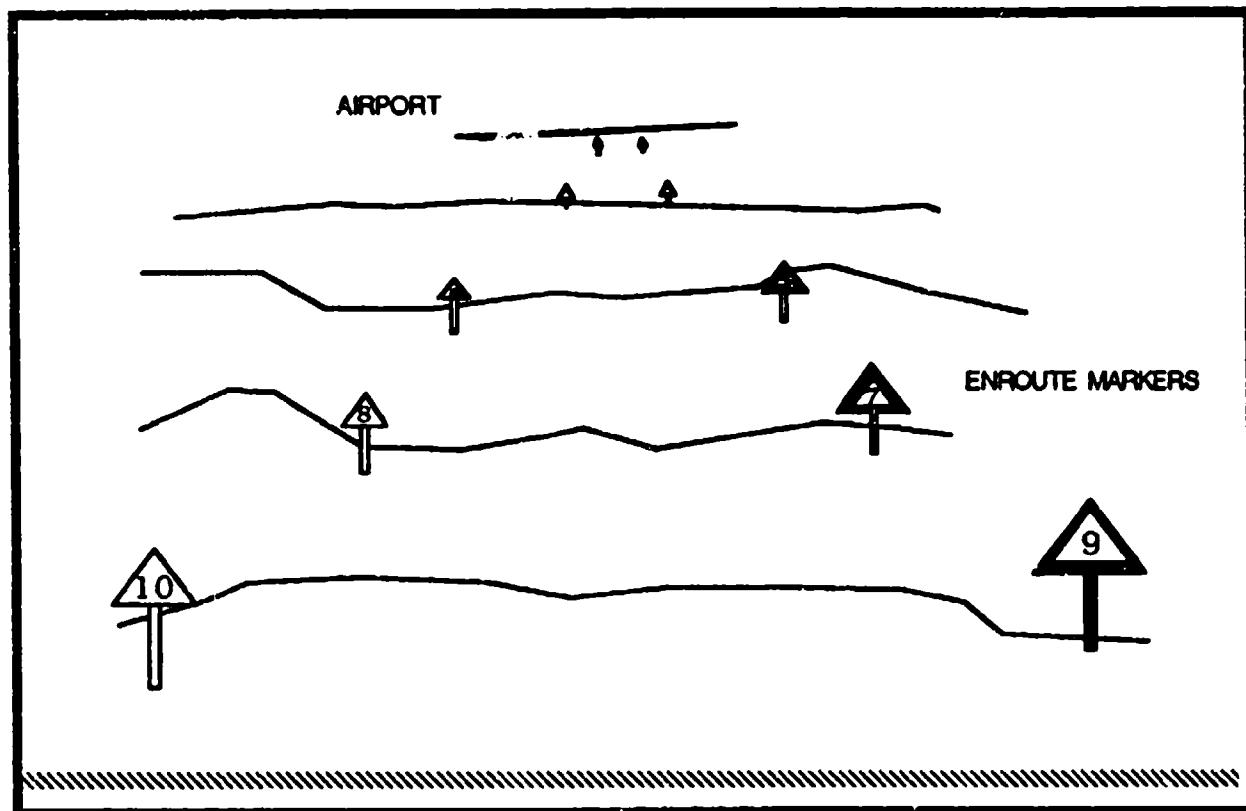


FIGURE 9. EXTENDED VISUAL AIRWAY LEADING TO AN AIRPORT

SPECIAL VISUAL APPROACH TO AIRPORT

Figure 10 shows a tiltrotor aircraft conducting a point-in-space approach to an arrival array which is a visual marking system of some sort which clearly identifies the beginning of a visual route. The route may be a highway, river, a set of lights, or a combination of lights and day markers as illustrated in figure 9. This visual airway or visual lead-in system terminates in a disciplined final arrival pattern to a hover objective volume and landing surface (heliport or vertiport (see figure 10)). The track of the aircraft is observed in the tower as the result of a continuous and automatic down-link of the aircraft's position based upon the outputs of an accurate on-board navigation system.

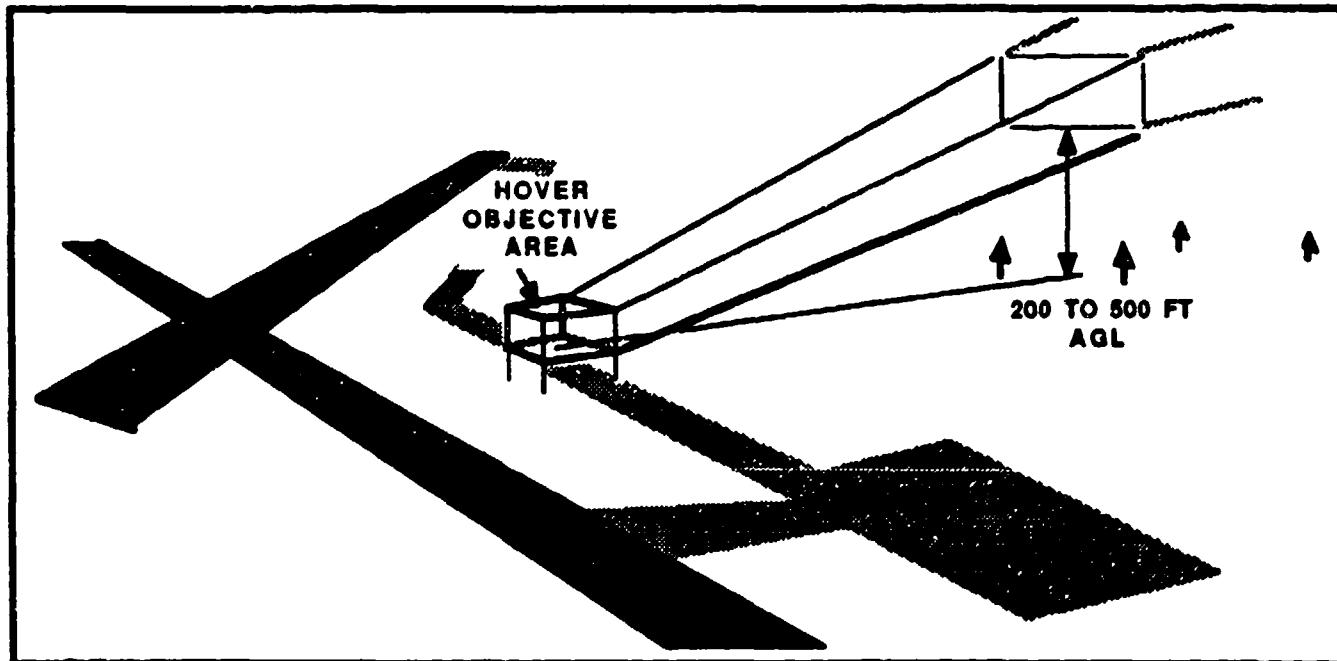


FIGURE 10. PROPOSED ARRIVAL AIRSPACE FOR VISUAL APPROACH TO AN AIRPORT OPERATING IFR

A highly developed infrastructure will include approaches like the one presented in figure 11. This is a steep approach and utilizes rectilinear guidance on final (starting at "a" in figure 11). This guidance window is as small as possible to minimize the need for protected airspace. While the buildings on final are obstructions, they are also landmarks and may be used to confirm that the aircraft is operating within approach constraints. This concept was developed as a result of analyzing the results of references 9 and 10, and first documented in reference 11.

In summary, this class of instrument approach represents one of the most complex forms of obstruction avoidance. In addition, it appears that the same equipments required to conduct en route VFR-DVC operations will also facilitate the extension of the visual segment of instrument approaches to city centers.

FOG OR HAZE OR LIGHT RAIN IN DARKNESS PRODUCES IMC OR DIFFICULT VISUAL CONDITIONS DURING A PRECISION APPROACH TO A CITY CENTER HELIPORT.

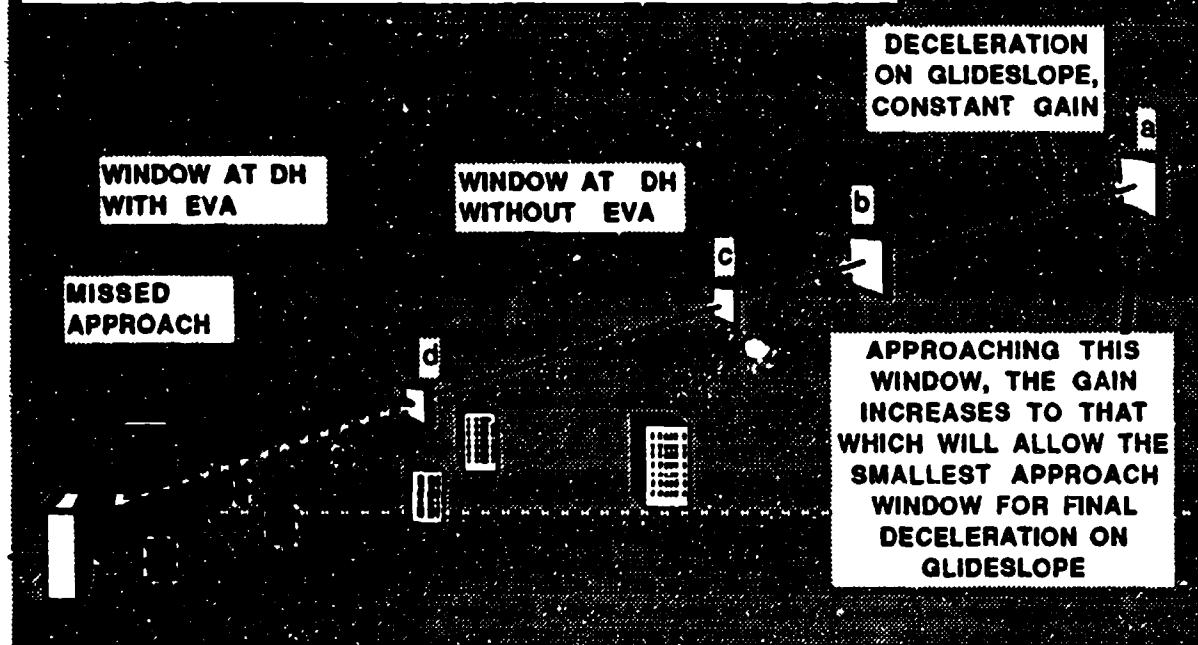


FIGURE 11: DESIGN CONDITIONS WHEN CONSIDERING FLIGHT CONTROL METHODS, ELECTRONIC VISION AIDS (EVA), AND WINDOWS FOR A FUTURE HELICOPTER INSTRUMENT APPROACH TO A CITY/TOWN HELIPORT
(Adapted from reference 11).

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(See also references on page 91.)